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(54) **VALVE TIMING CONTROL APPARATUS FOR INTERNAL COMBUSTION ENGINE**

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F01L 1/34 (2006.01)

(52) **U.S. Cl.**
USPC **701/103**; 123/90.15

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USPC 701/101–105, 112–115; 123/90.1, 123/90.15–90.17, 90.21–90.24, 90.31, 321, 123/322
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,708,657	B2 *	3/2004	Iwaki et al.	123/90.17
7,181,330	B2 *	2/2007	Shimojo et al.	701/102
7,191,746	B2 *	3/2007	Nakamura	123/179.3
7,441,524	B2	10/2008	Okamoto et al.	
2003/0000489	A1 *	1/2003	Majima et al.	123/90.17
2004/0010363	A1 *	1/2004	Watanuki et al.	701/114
2006/0207536	A1 *	9/2006	Todo et al.	123/90.16
2006/0229797	A1 *	10/2006	Sawada et al.	701/114
2006/0231052	A1 *	10/2006	Yamanaka	123/90.17
2007/0221151	A1 *	9/2007	Kadowaki	123/90.17
2008/0017149	A1 *	1/2008	Kokubo et al.	123/90.16
2008/0288155	A1 *	11/2008	Watanabe et al.	701/102
2009/0007862	A1 *	1/2009	Nakamura et al.	123/90.12
2009/0007865	A1 *	1/2009	Nguyen et al.	123/90.15
2009/0018754	A1 *	1/2009	Hano et al.	701/103
2009/0125216	A1 *	5/2009	Watanabe et al.	701/105
2009/0183701	A1 *	7/2009	Nguyen et al.	123/90.15

FOREIGN PATENT DOCUMENTS

JP 2005-299640 A 10/2005

* cited by examiner

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(57) **ABSTRACT**

A valve timing control apparatus includes a phase varying mechanism arranged to vary a relative rotational phase of a cam shaft with respect to a crank shaft; a driving mechanism arranged to provide a driving force to the phase varying mechanism by energization; a control mechanism configured to control a current applied to the driving mechanism; and a phase angle sensing mechanism arranged to sense the relative rotational phase of the cam shaft with respect to the crank shaft, and to have a detection period longer than a control period of the control mechanism in accordance with an engine operating state. The control mechanism is configured to repeat increasing and decreasing of the current applied to the driving mechanism when the phase varying mechanism continuously varies the relative rotational phase of the cam shaft with respect to the crank shaft by a predetermined angle or more.

21 Claims, 10 Drawing Sheets

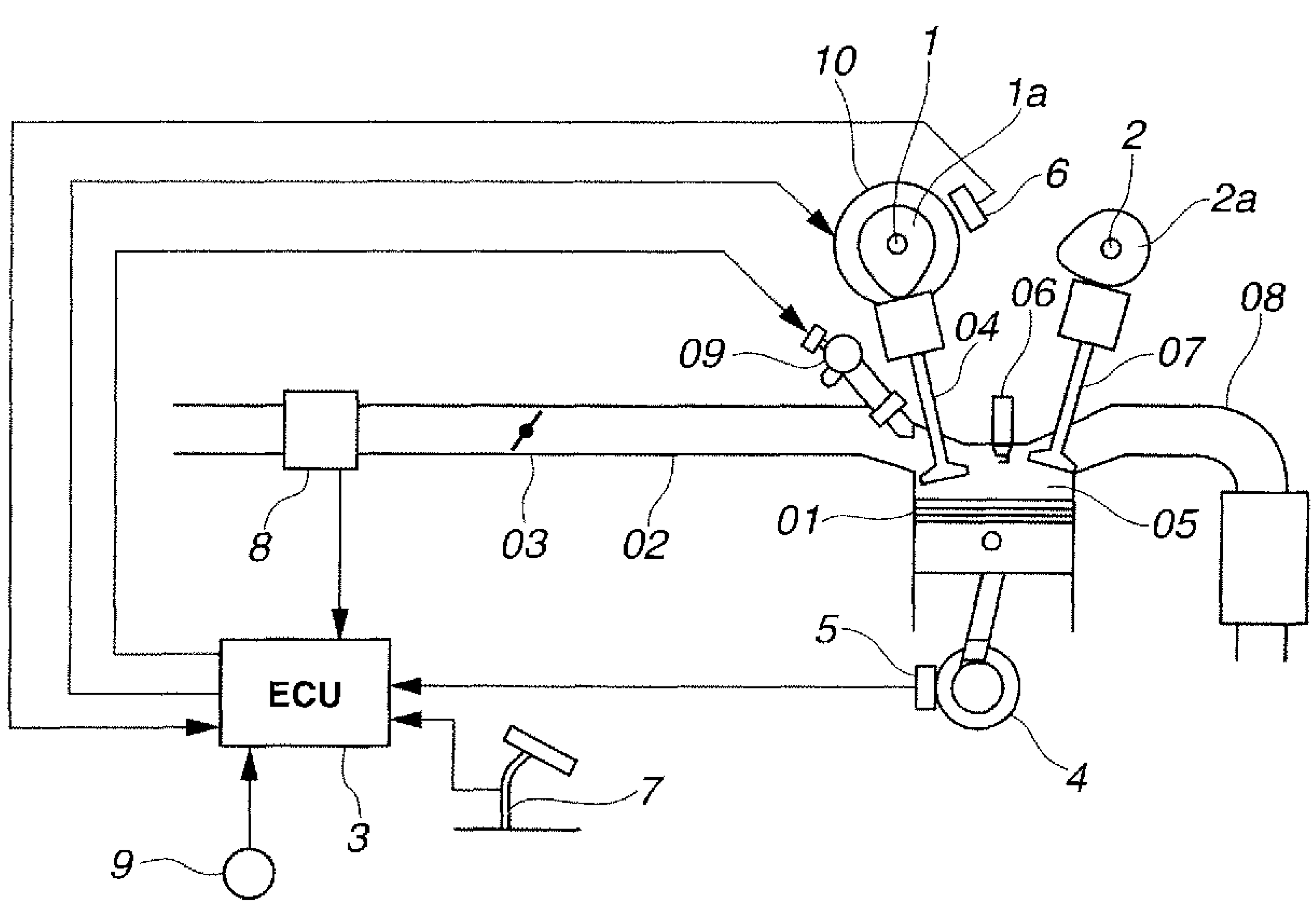


FIG.1

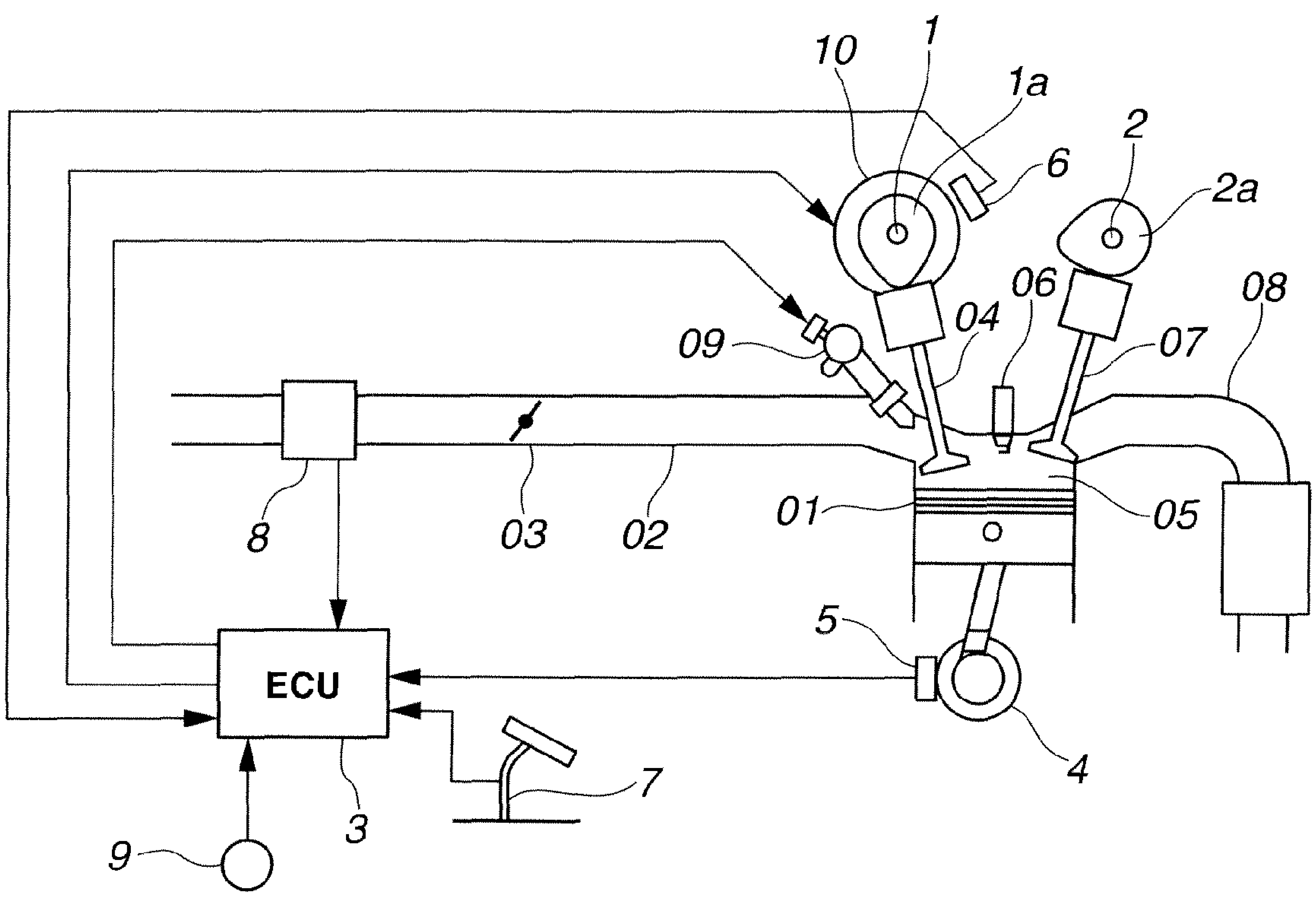


FIG.2

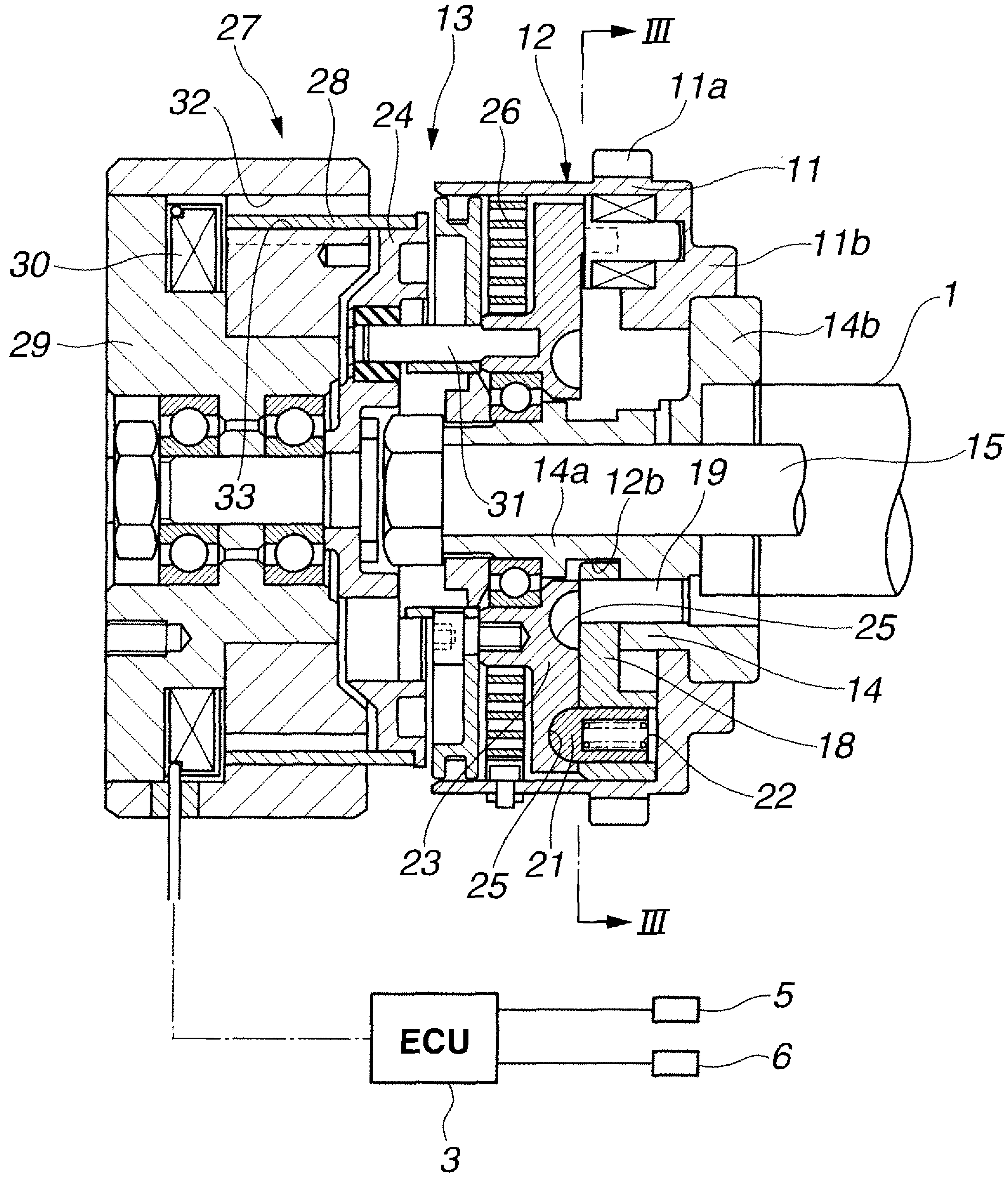

27
13
12
III
32
28
24
26
11a
11
30
11b
14b
1
29
15
33
31
14a
12b
19
25
14
18
22
23
25
21
III
ECU
5
6
3

FIG.3

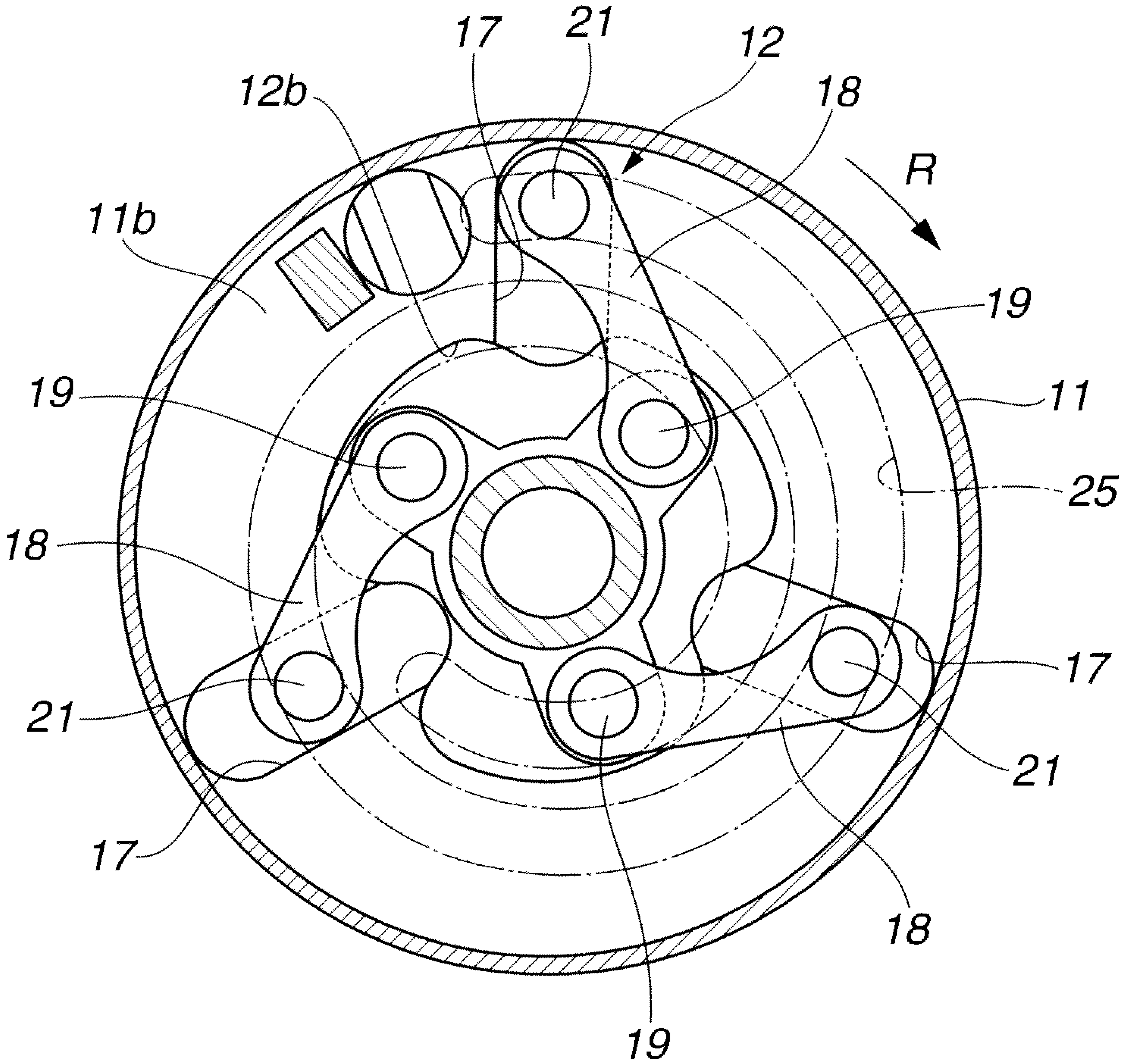


FIG.4A

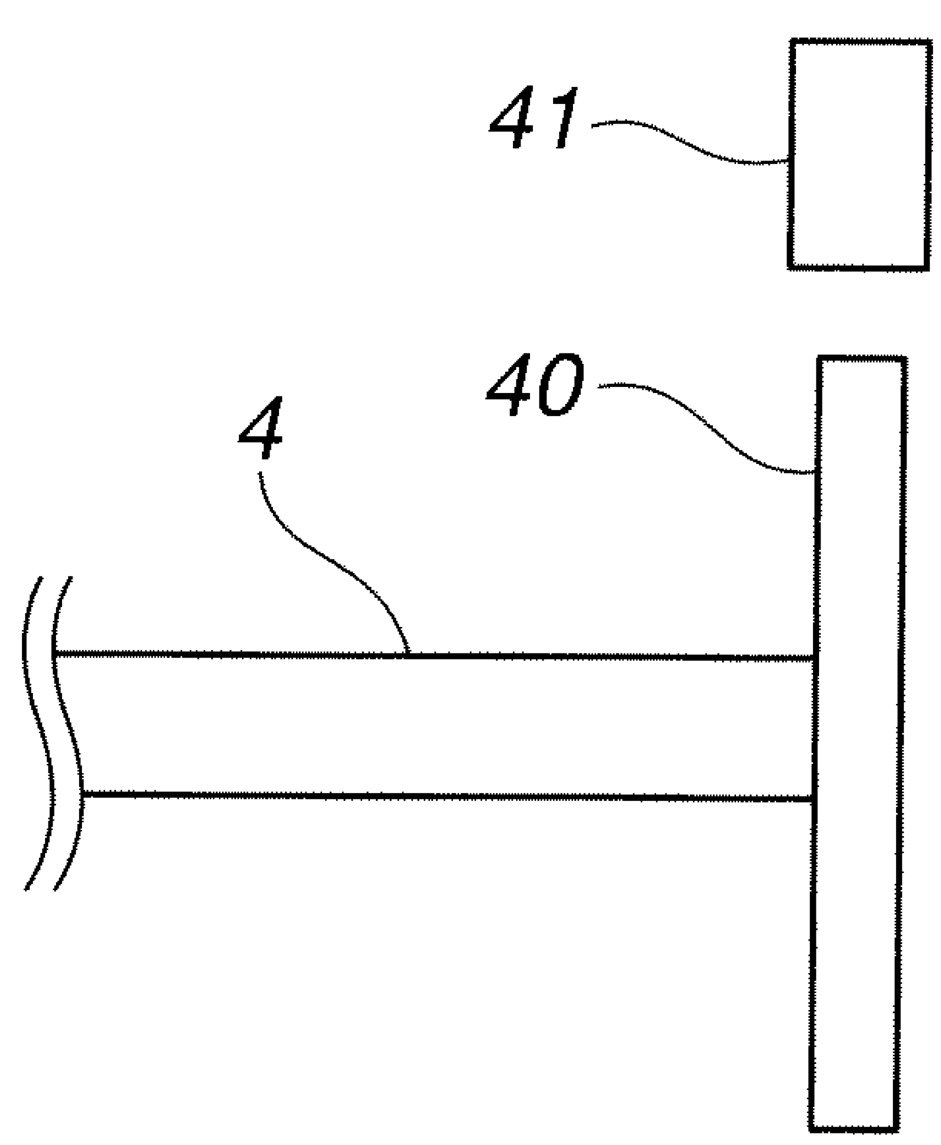


FIG.4B

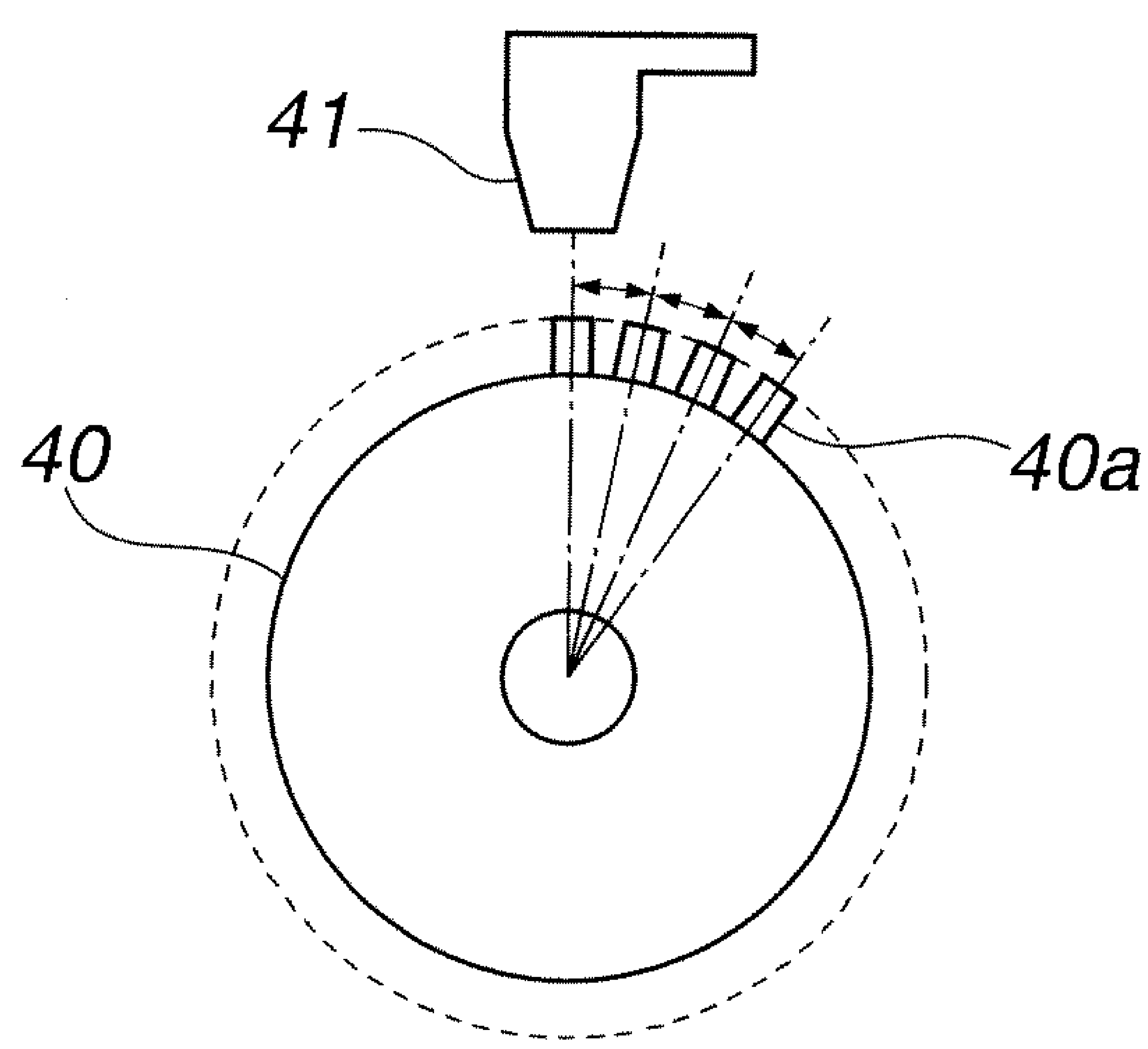


FIG.5A

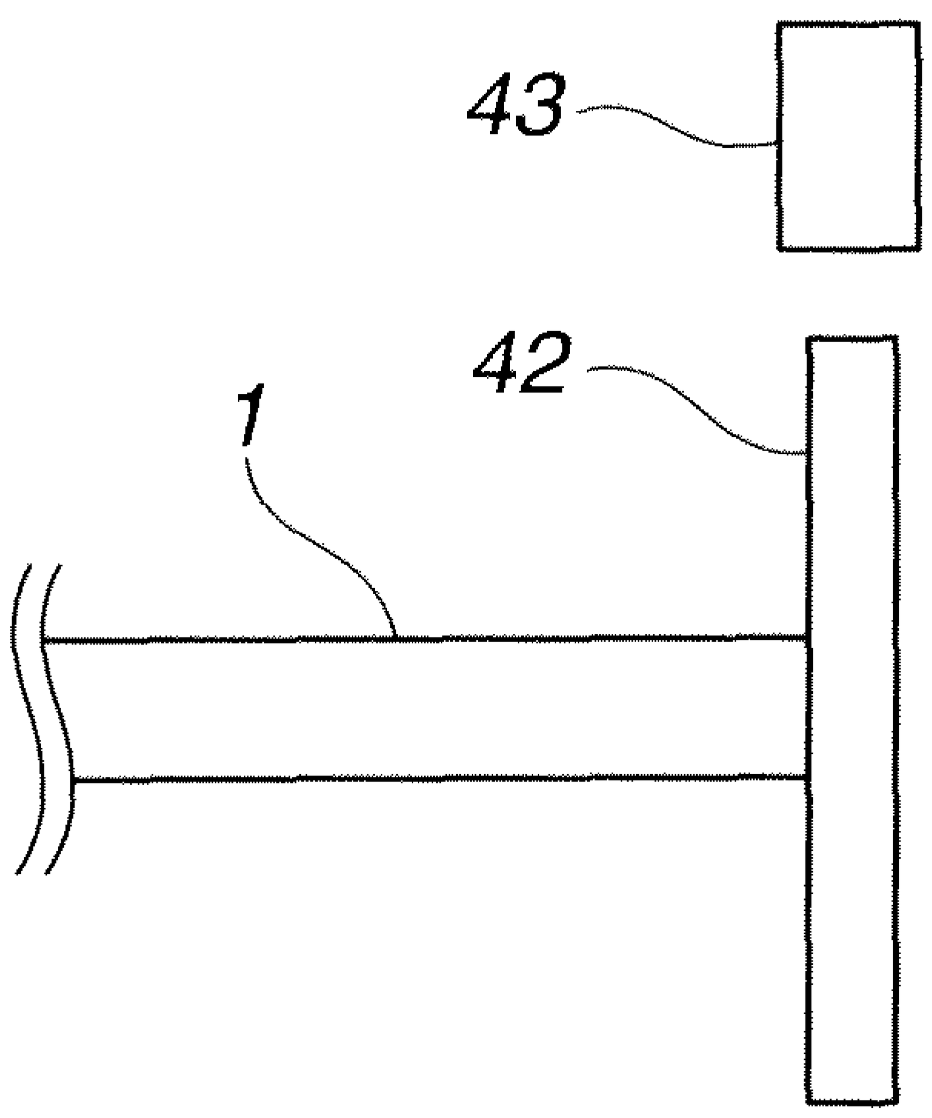


FIG.5B

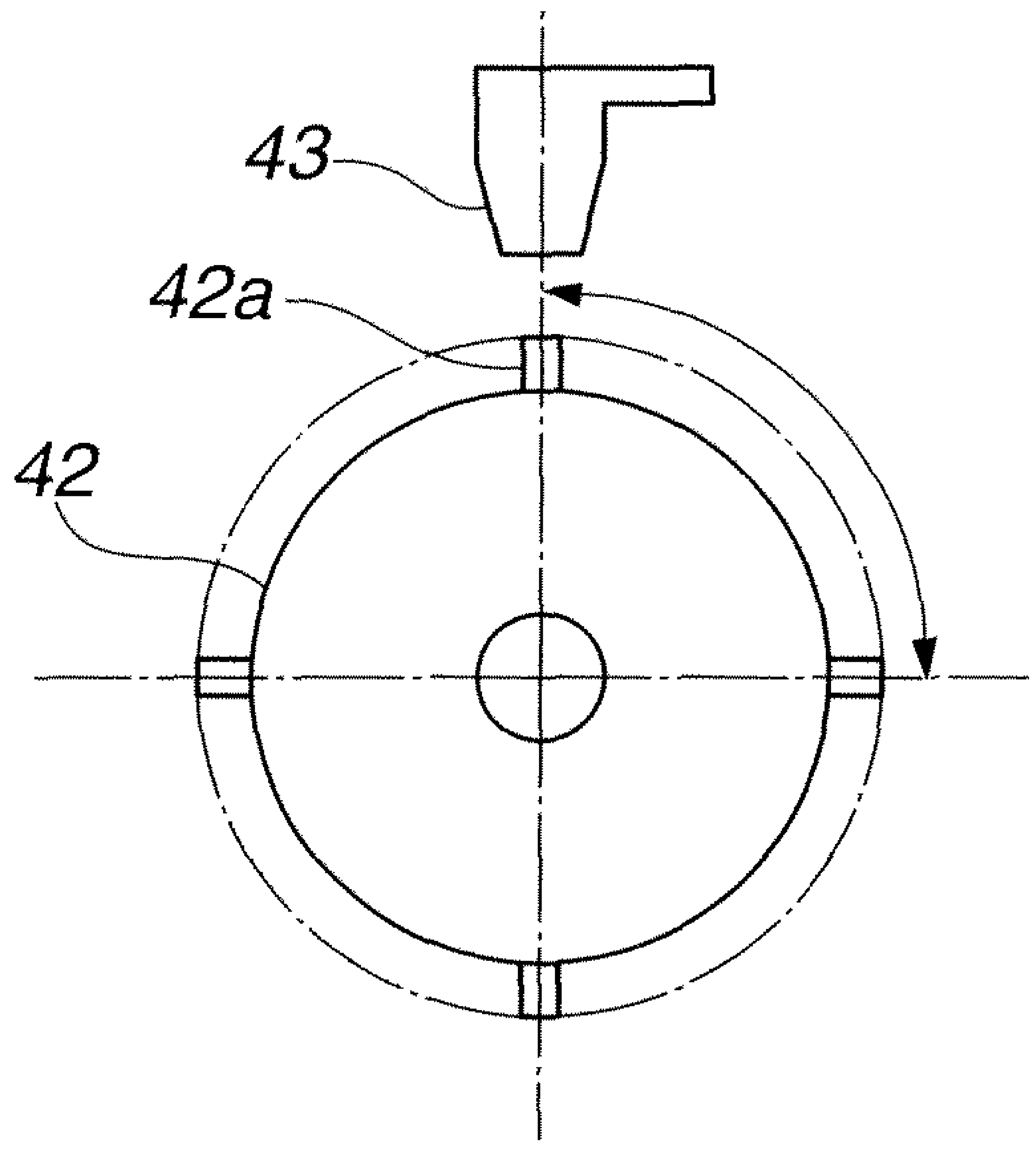


FIG.6

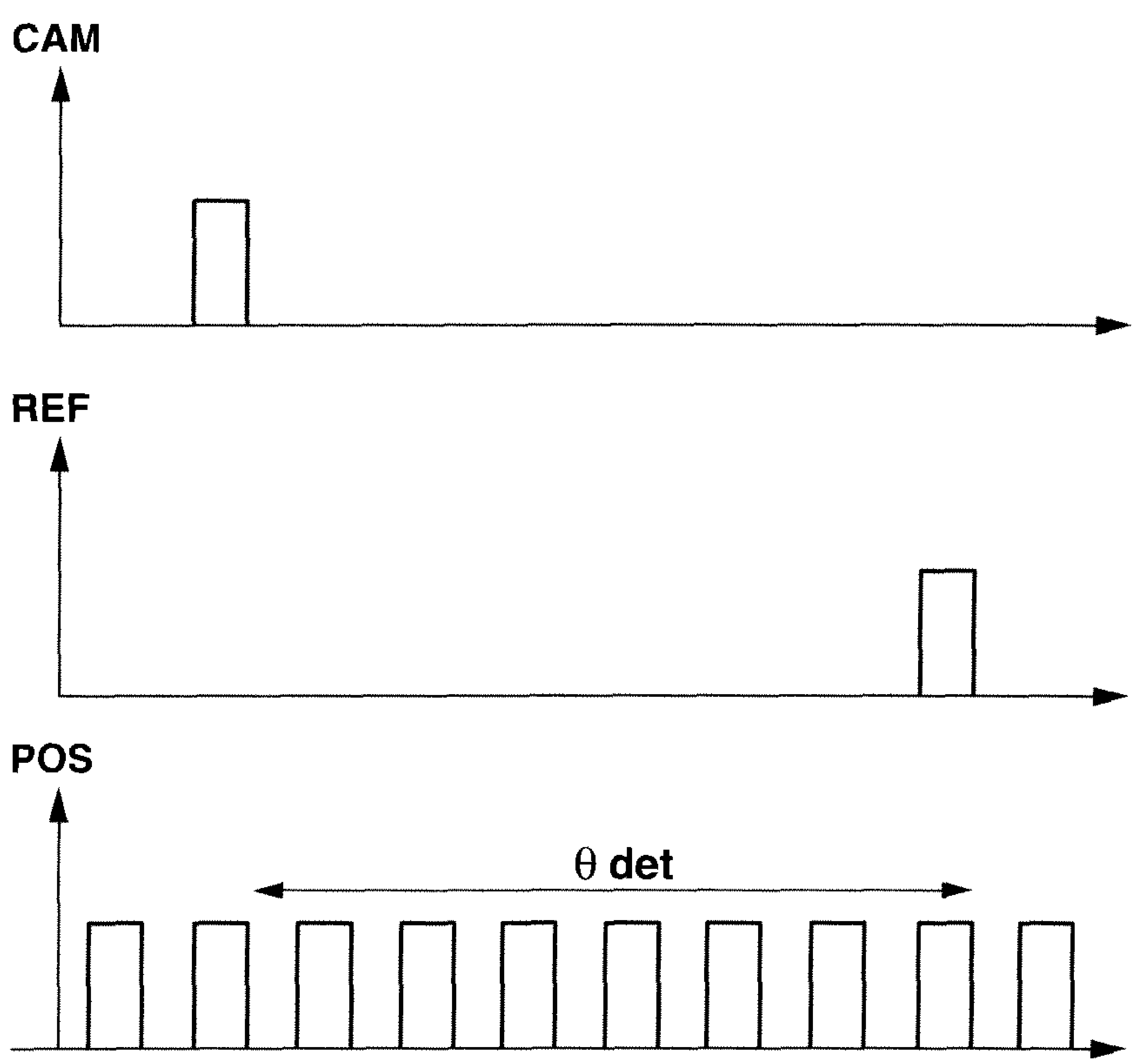


FIG.7

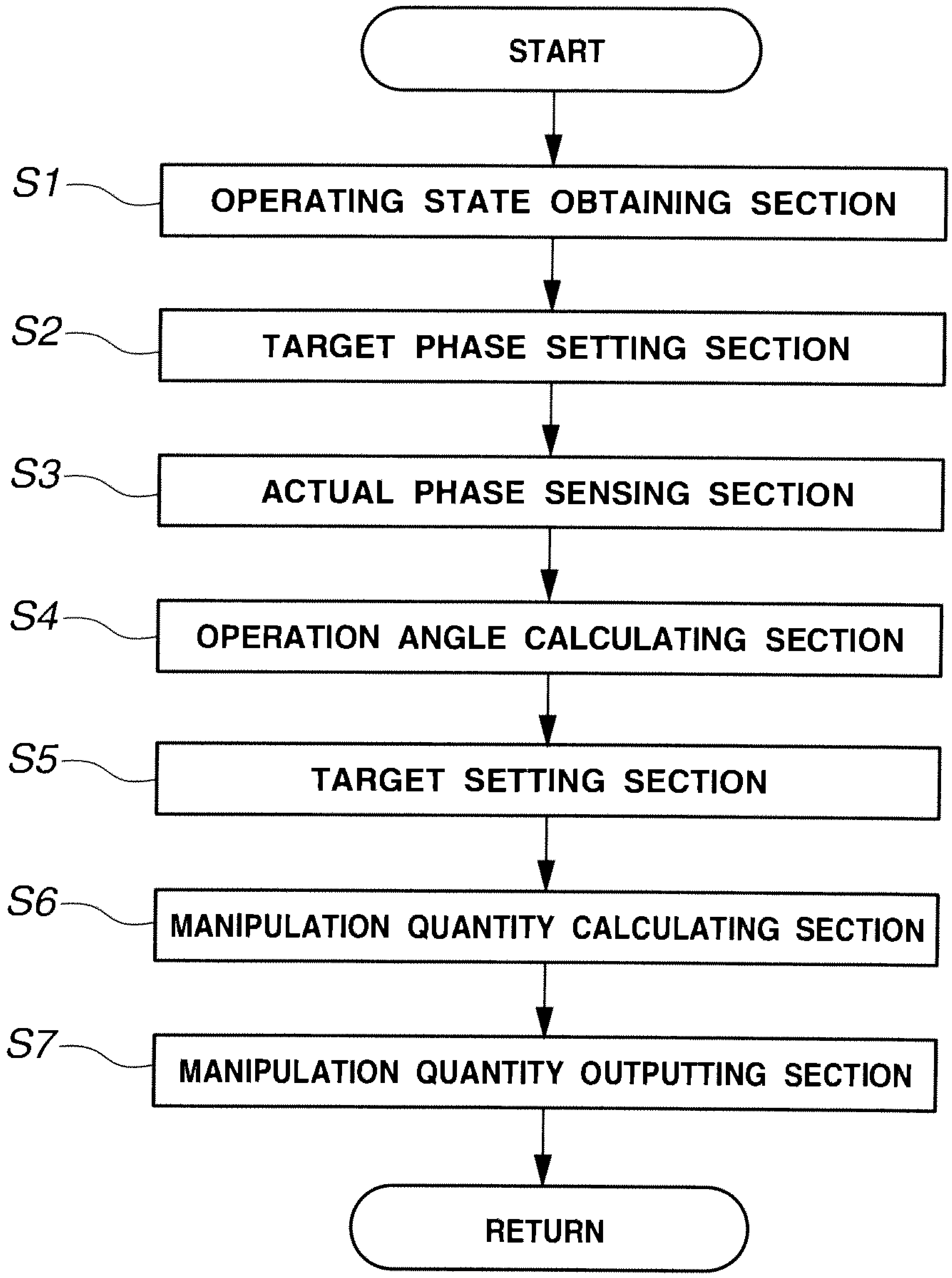

START
S1
OPERATING STATE OBTAINING SECTION
S2
TARGET PHASE SETTING SECTION
S3
ACTUAL PHASE SENSING SECTION
S4
OPERATION ANGLE CALCULATING SECTION
S5
TARGET SETTING SECTION
S6
MANIPULATION QUANTITY CALCULATING SECTION
S7
MANIPULATION QUANTITY OUTPUTTING SECTION
RETURN

FIG.8

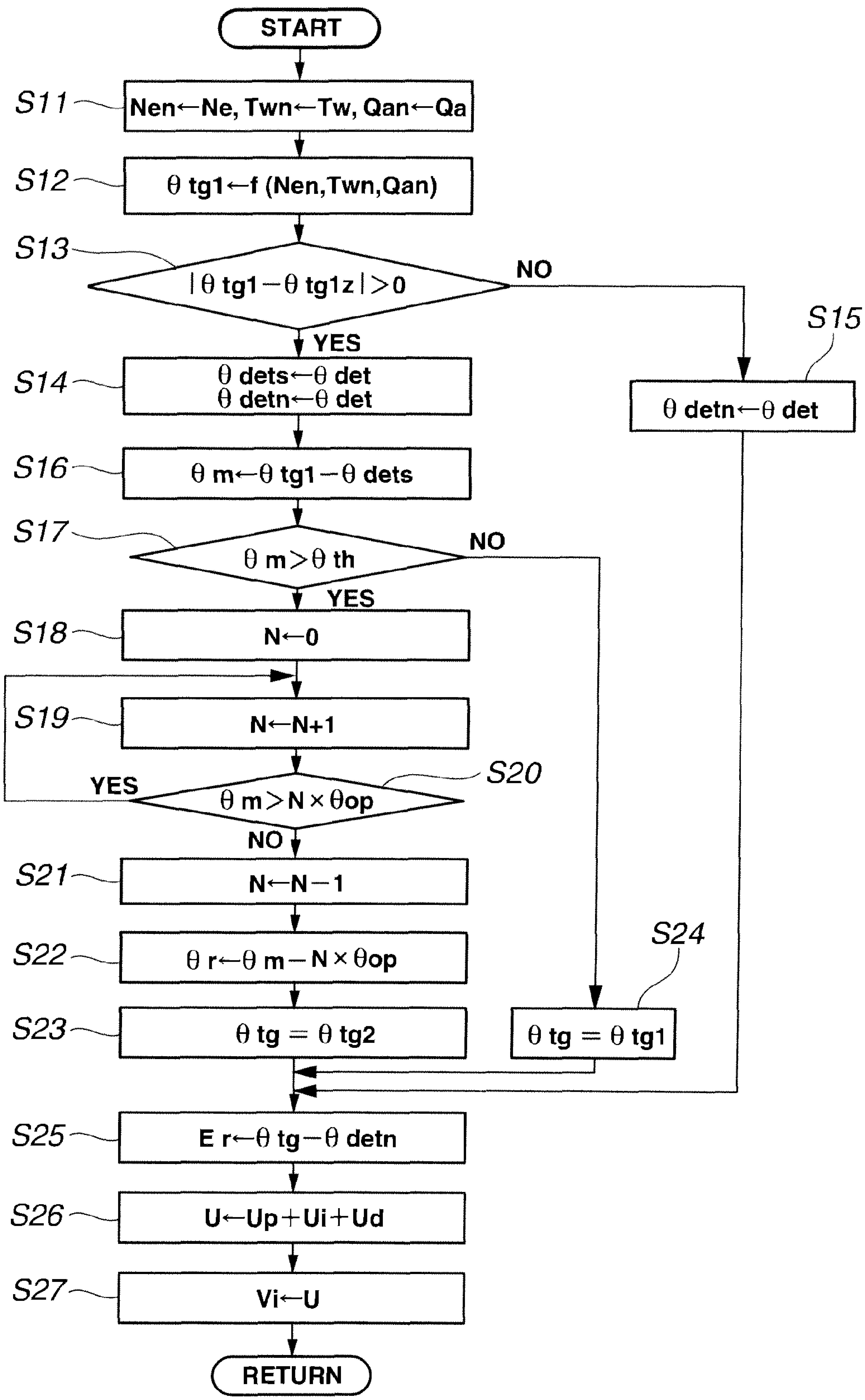

START
S11
Nen←Ne, Twn←Tw, Qan←Qa
S12
θ tg1←f (Nen,Twn,Qan)
S13
|θ tg1−θ tg1z|>0
NO
YES
S14
θ dets←θ det
θ detn←θ det
S15
θ detn←θ det
S16
θ m←θ tg1−θ dets
S17
θ m>θ th
NO
YES
S18
N←0
S19
N←N+1
YES
S20
θ m>N×θop
NO
S21
N←N−1
S22
θ r←θ m−N×θop
S23
θ tg = θ tg2
S24
θ tg = θ tg1
S25
E r←θ tg−θ detn
S26
U←Up+Ui+Ud
S27
Vi←U
RETURN

FIG.9

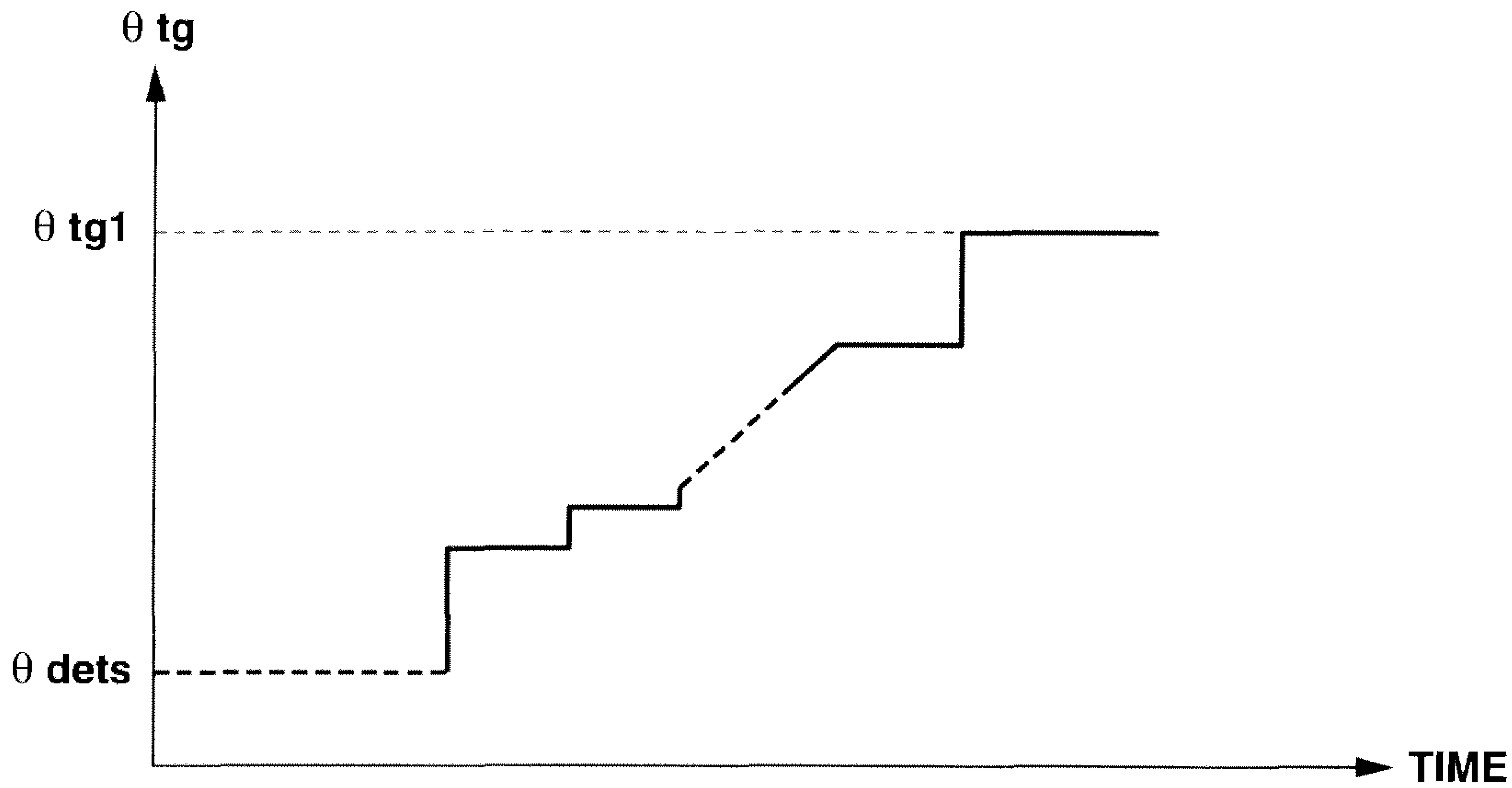


FIG.10

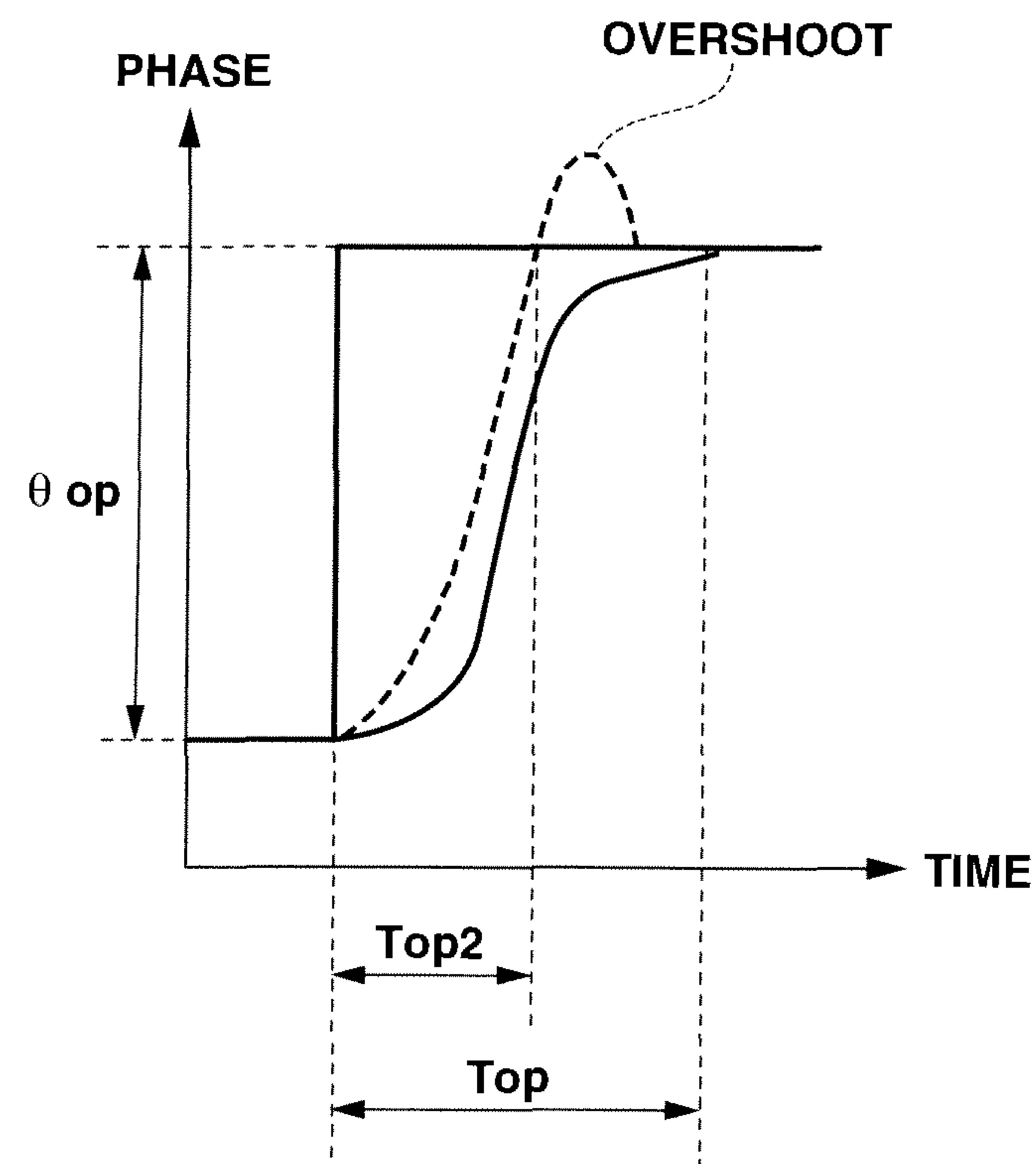


FIG.11

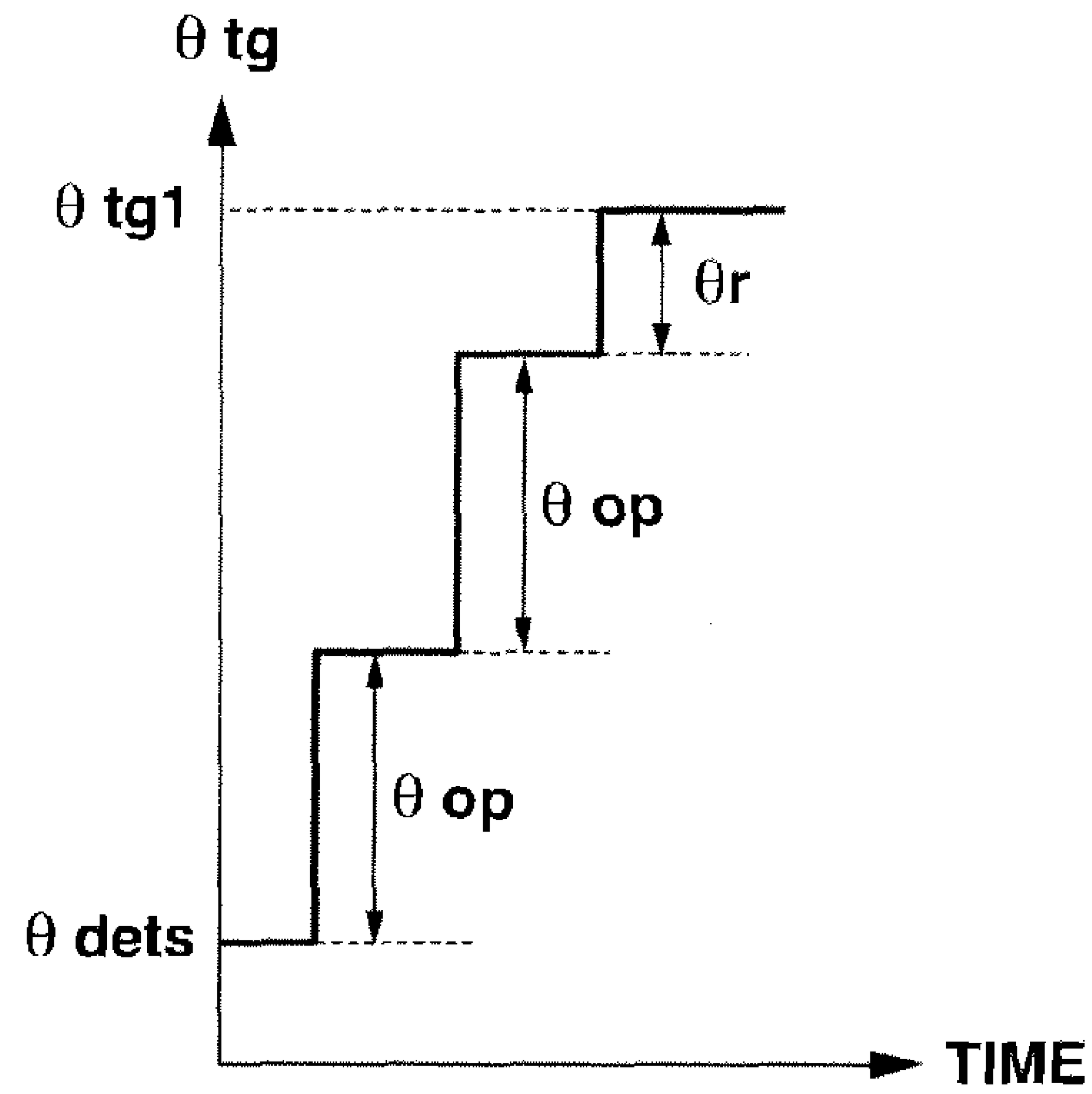


FIG.12

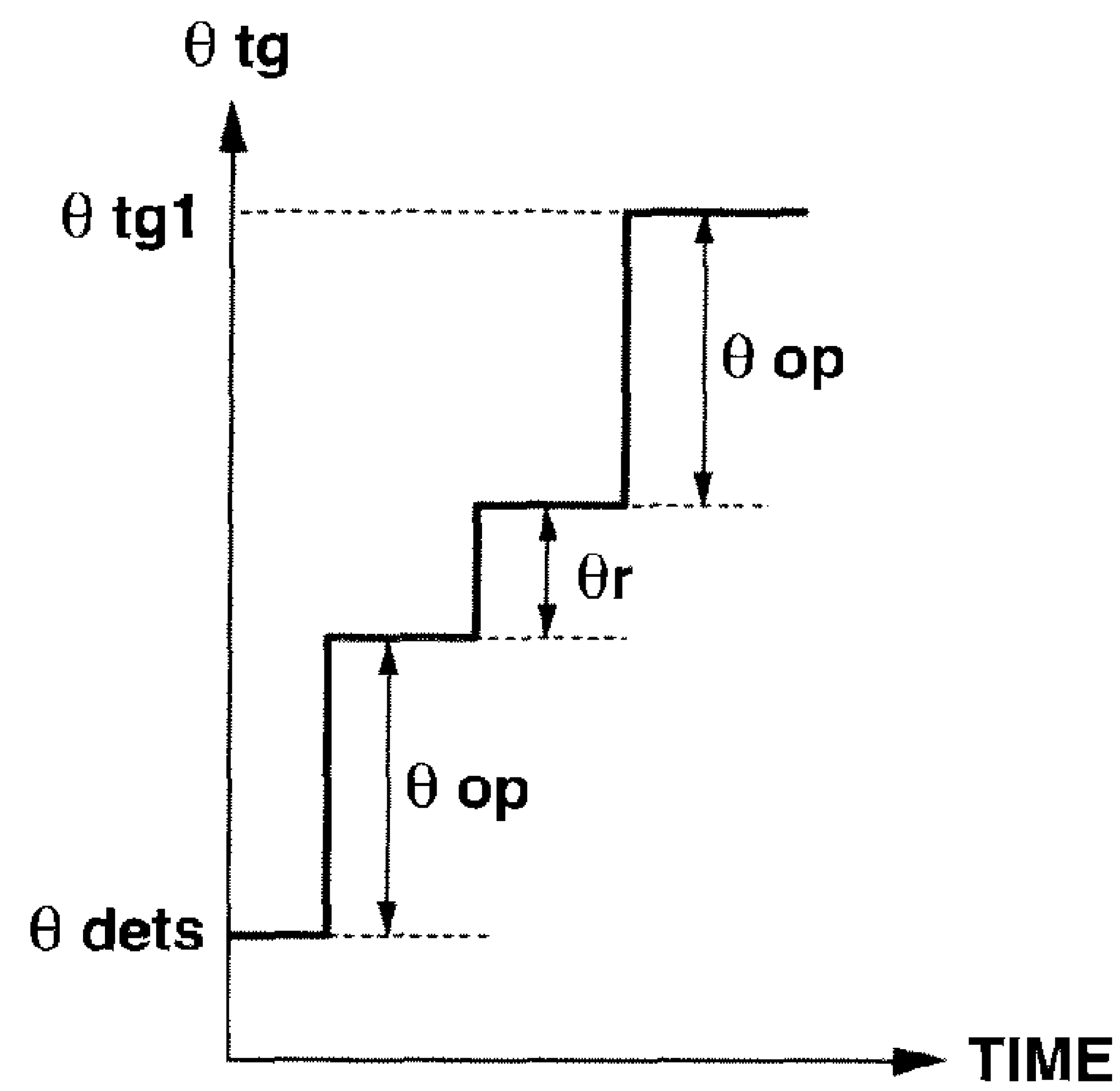


FIG.13

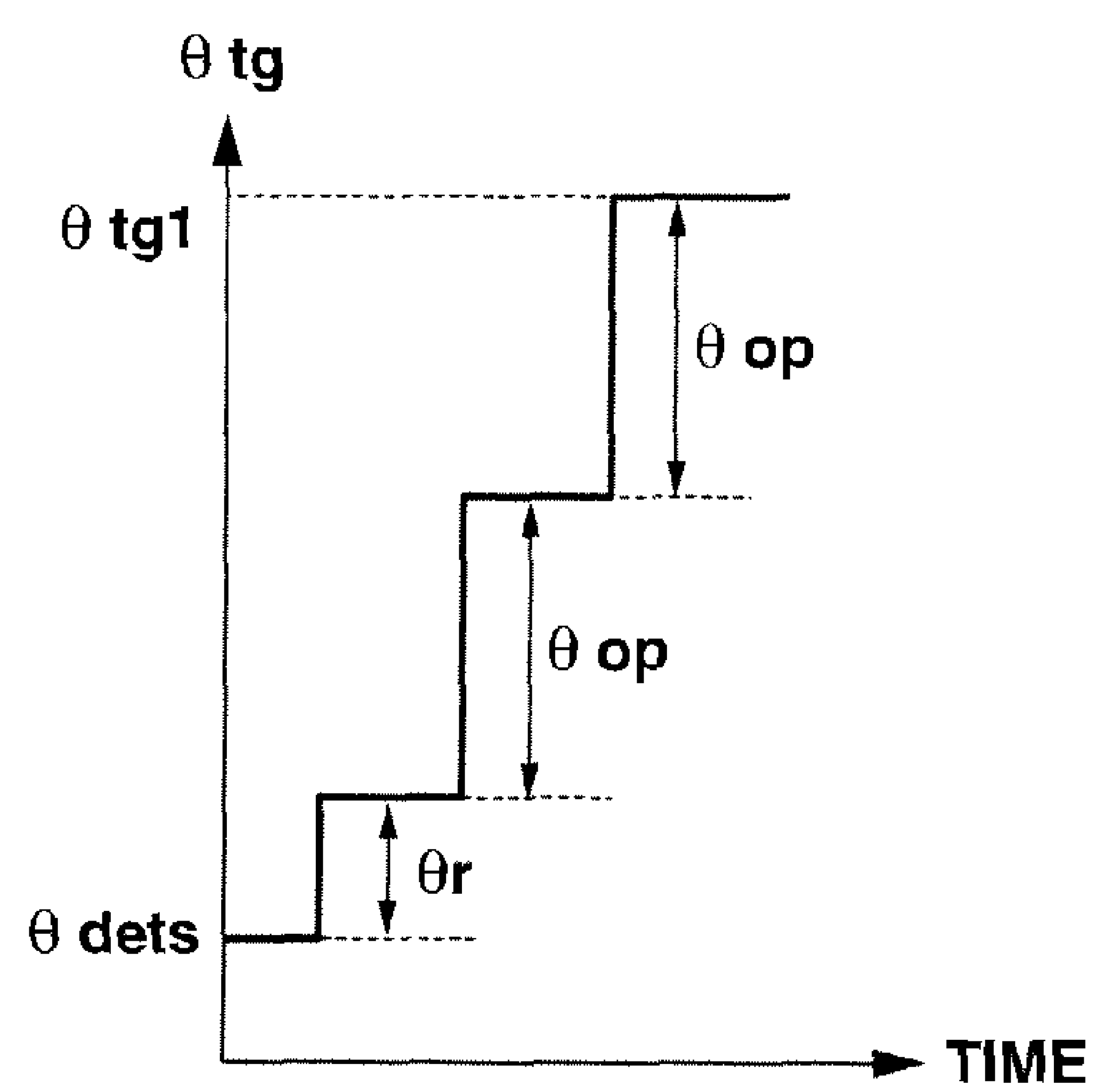


FIG.14

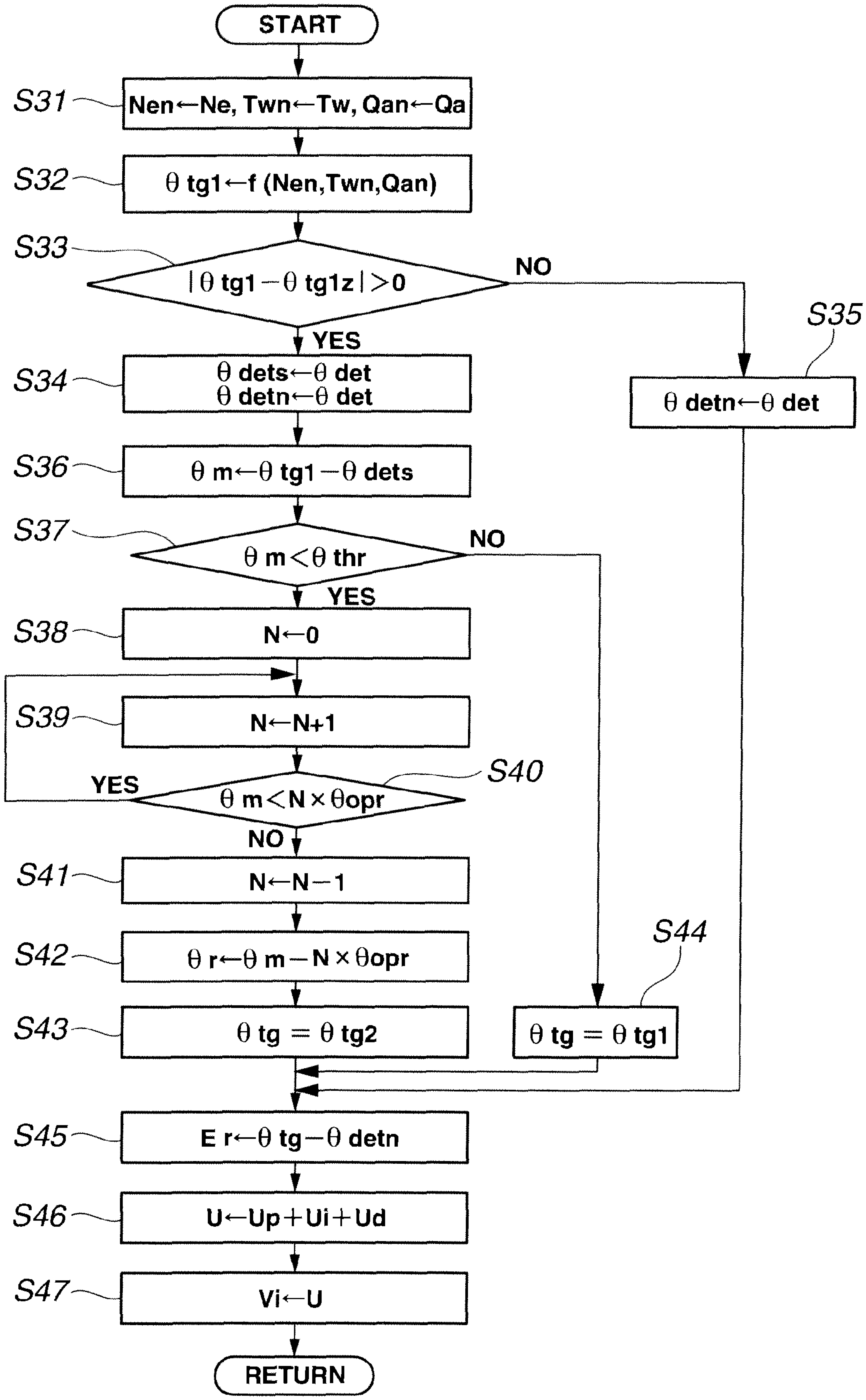

START
S31
Nen←Ne, Twn←Tw, Qan←Qa
S32
θ tg1←f (Nen,Twn,Qan)
S33
|θ tg1 − θ tg1z| > 0
NO
YES
S34
θ dets←θ det
θ detn←θ det
S35
θ detn←θ det
S36
θ m←θ tg1 − θ dets
S37
θ m < θ thr
NO
YES
S38
N←0
S39
N←N+1
S40
θ m < N × θopr
YES
NO
S41
N←N − 1
S42
θ r←θ m − N × θopr
S43
θ tg = θ tg2
S44
θ tg = θ tg1
S45
E r←θ tg − θ detn
S46
U←Up + Ui + Ud
S47
Vi←U
RETURN

FIG.15

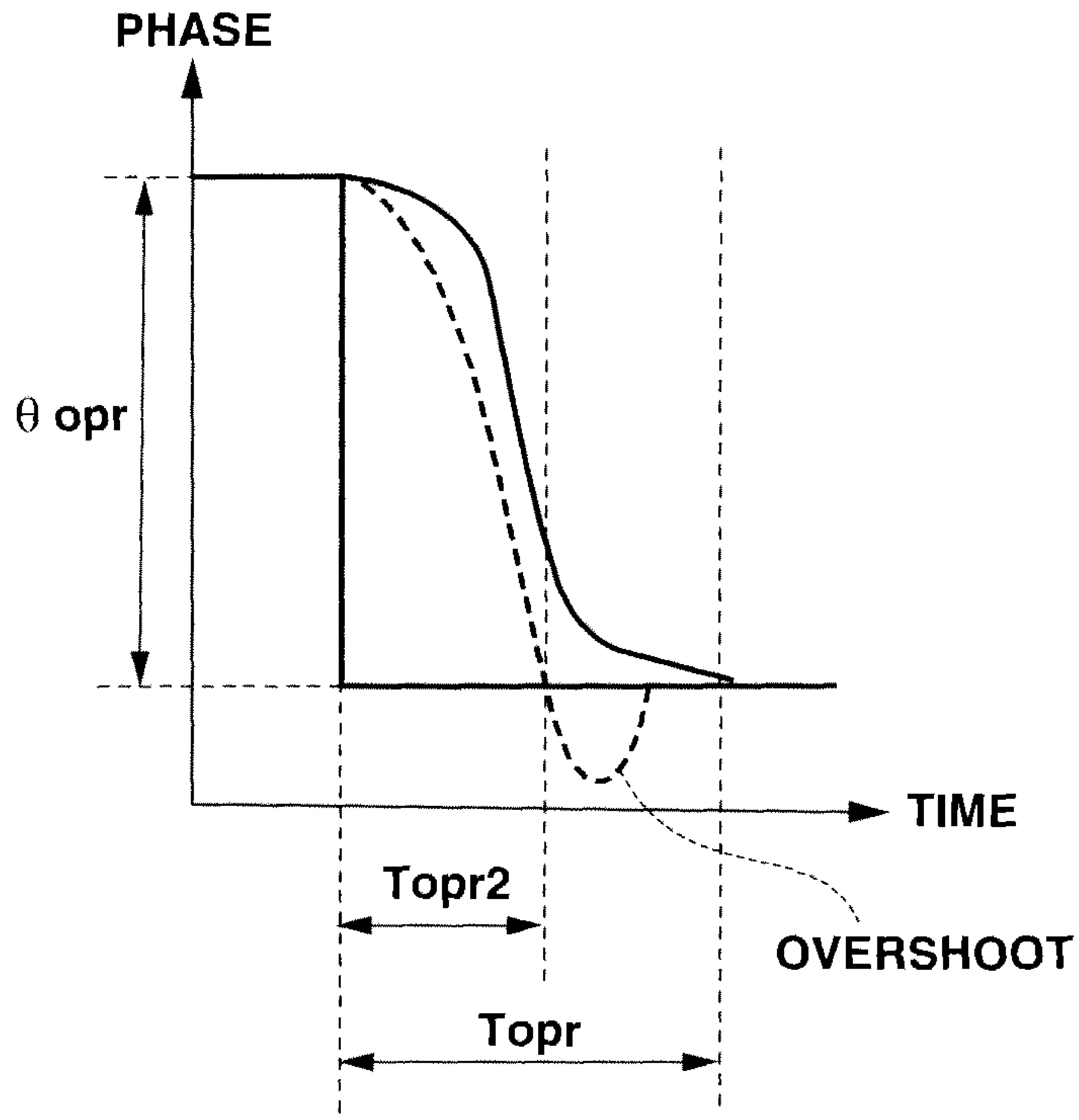
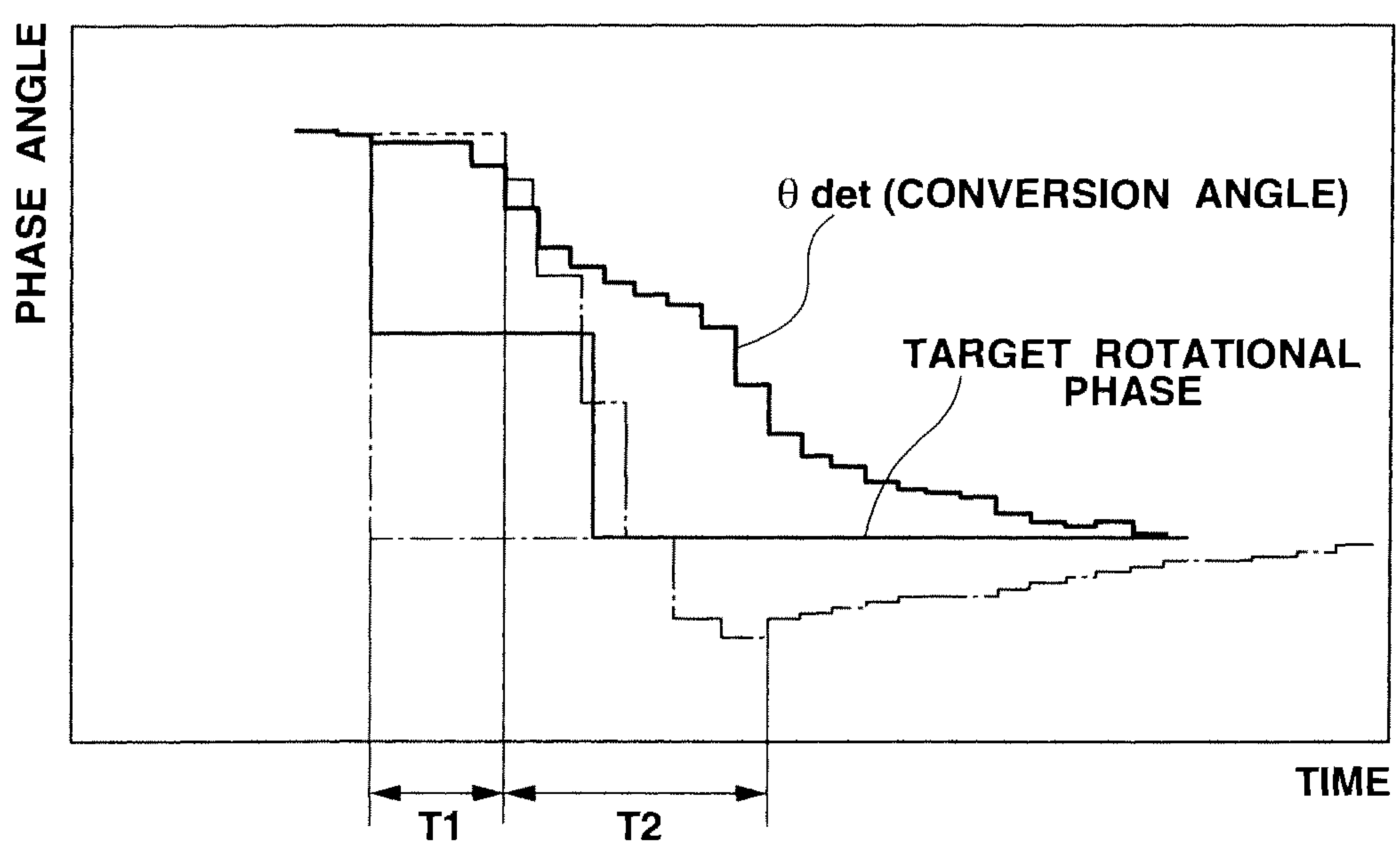

PHASE
θ opr
TIME
Topr2
OVERSHOOT
Topr

FIG.16


PHASE ANGLE
θ det (CONVERSION ANGLE)
TARGET ROTATIONAL PHASE
TIME
T1
T2

VALVE TIMING CONTROL APPARATUS FOR INTERNAL COMBUSTION ENGINE

BACKGROUND OF THE INVENTION

This invention relates to a valve timing control apparatus configured to vary a relative rotational phase of a cam shaft with respect to a crank shaft of an internal combustion engine, and to vary a valve timing (opening and closing timing) of an intake valve or an exhaust valve.

U.S. Pat. No. 7,441,524 (corresponding to Japanese Patent Application Publication No. 2005-299640) shows a valve timing control apparatus including a rotational phase sensing section configured to sense a relative rotational phase between a crank shaft and a cam shaft at an arbitrary timing. This valve timing control apparatus is controlled by the rotational phase sensed by the rotational phase sensing section.

This valve timing control apparatus can sense the relative rotational phase even in a period shorter than a rotation period of the cam shaft. The feedback control of the valve timing control can be performed even at the low rotation speed so as to correspond the control period of the valve timing to the detection period of the relative rotational phase. Accordingly, it is possible to attain the high-responsive/high-accurate valve timing control.

That is, in a case in which there is roughness of the detection period of the rotational phase sensing section irrespective of the engine rotation, the phase is separated from the target phase by the overshoot after the arrival to the target phase angle, so that it is adversely affected. Accordingly, the rotational phase sensing section with the high accuracy is used so as to suppress the overshoot, and to improve the control response and the control accuracy.

SUMMARY OF THE INVENTION

However, the valve timing control apparatus has a common characteristic to have deteriorated controllability for response delay of actuator and a large sliding resistance immediately after the start of the operation, and to thereby tend to cause the overshoot. Moreover, in the conventional valve timing control apparatus, the expensive rotational phase sensing section is used for suppressing the overshoot caused by the roughness of the detection period of the rotational phase sensing section. Consequently, the cost is increased.

It is, therefore, an object of the present invention to provide a valve timing control apparatus (VTC) devised to suppress the overshooting at the operation of the valve timing control apparatus, and to decrease the cost.

According to one aspect of the present invention, a valve timing control apparatus for an internal combustion engine which is configured to control an opening timing or a closing timing of an intake valve or an exhaust valve, the valve timing control apparatus comprises: a phase varying mechanism arranged to vary a relative rotational phase of a cam shaft with respect to a crank shaft; a driving mechanism arranged to provide a driving force to the phase varying mechanism by energization; a control mechanism configured to control a current applied to the driving mechanism; and a phase angle sensing mechanism arranged to sense the relative rotational phase of the cam shaft with respect to the crank shaft, and to have a detection period longer than a control period of the control mechanism in accordance with an engine operating state, the control mechanism configured to repeat increasing and decreasing of the current applied to the driving mechanism when the phase varying mechanism continuously varies the relative rotational phase of the cam shaft with respect to the crank shaft by a predetermined angle or more.

According to another aspect of the invention, a valve timing control apparatus for an internal combustion engine which is configured to control an opening timing or a closing timing of an intake valve or an exhaust valve, the valve timing control apparatus comprises: a phase varying mechanism arranged to vary a relative rotational phase of a cam shaft with respect to a crank shaft; a driving mechanism arranged to provide a driving force to the phase varying mechanism by energization; a control mechanism configured to perform a duty control of a current applied to the driving mechanism; and a phase angle sensing mechanism arranged to sense the relative rotational phase of the cam shaft with respect to the crank shaft, and to have a detection period longer than a control period of the control mechanism in accordance with an engine operating state, the control mechanism configured to repeat increasing and decreasing of a duty ratio for the driving mechanism when the phase varying mechanism continuously varies the relative rotational phase of the cam shaft with respect to the crank shaft by a predetermined angle or more.

According to still another aspect of the invention, a valve timing control apparatus for an internal combustion engine which is configured to control an opening timing or a closing timing of an intake valve or an exhaust valve, the valve timing control apparatus comprises: a phase varying mechanism arranged to vary a relative rotational phase of a cam shaft with respect to a crank shaft; a driving mechanism arranged to provide a driving force to the phase varying mechanism by energization; a control mechanism configured to control a current applied to the driving mechanism; and a phase angle sensing mechanism arranged to sense the relative rotational phase of the cam shaft with respect to the crank shaft, and to have a detection period longer than a control period of the control mechanism in accordance with an engine operating state, the phase varying mechanism arranged to repeat increasing and decreasing of a movement speed when the phase varying mechanism continuously varies the relative rotational phase of the cam shaft with respect to the crank shaft by a predetermined angle or more.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view showing an engine employing a valve timing control apparatus according to a first embodiment of the present invention.

FIG. **2** is a sectional view showing the valve timing control apparatus of FIG. **1**.

FIG. **3** is a sectional view taken along a section line III-III of FIG. **2**.

FIG. **4**A is a side view showing a crank angle sensor of the valve timing control apparatus of FIG. **2**. FIG. **4**B is a front view showing the crank angle sensor of FIG. **4**A.

FIG. **5**A is a side view showing a cam angle sensor of the valve timing control apparatus of FIG. **2**. FIG. **5**B is a front view showing the cam angle sensor of FIG. **5**A.

FIG. **6** is a view showing pulse signals obtained by the crank angle sensor and the cam angle sensor.

FIG. **7** is a block diagram showing a basic structure of an ECU of the valve timing control apparatus of FIG. **2**.

FIG. **8** is a flowchart showing a control process of the ECU of FIG. **2**.

FIG. **9** is a characteristic view showing a pattern example in which a target phase is varied.

FIG. **10** is a characteristic view showing a target phase width and its duration which show an optimal response in the valve timing control apparatus of FIG. **2**.

FIG. **11** is a characteristic view showing a first method of dividing a normal target phase by a width of an appropriate response.

FIG. **12** is a characteristic view showing a second method of dividing the normal target phase by the width of the appropriate response.

FIG. **13** is a characteristic view showing a first method of dividing the normal target phase by the width of the appropriate response.

FIG. **14** is a flowchart showing a control process of an ECU in a variable valve control apparatus according to a second embodiment of the present invention.

FIG. **15** is a characteristic view showing a target phase width and its duration which show an optimal response in the valve timing control apparatus according to the second embodiment.

FIG. **16** is a characteristic view showing an operation response of the valve timing control apparatus according to the first and second embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, a valve timing control apparatus of an internal combustion engine according to embodiments of the present invention will be illustrated with reference to the drawings.

In these embodiments described later, the present invention is applied to a valve actuating apparatus on the intake side of an inline four cylinder engine. A structure of the cylinder is not limited to this structure.

FIG. **1** is a schematic view showing the entirety of the internal combustion engine. An intake passage **02** is formed within an engine body **01** including a cylinder block and a cylinder head. A throttle valve **03** is formed within intake passage **02**. The air is sucked through throttle valve **03** and an intake valve **04** into a combustion chamber **05**. A spark plug **06** for the ignition of the air-fuel mixture is provided within combustion chamber **05**. The exhaust gas flows through an exhaust valve **07** into an exhaust passage **08**. The exhaust gas is purified by a catalyst mounted to exhaust passage **08**, and discharged to the atmosphere.

Intake valve **04** and exhaust valve **07** are controlled to open and close by spring force of valve springs (not shown) and driving cams **1***a* and **2***a* provided to an intake cam shaft **1** and an exhaust cam shaft **2**.

A fuel injector **09** is provided to the intake port of each cylinder, and controlled by an engine control unit (ECU) **3** to inject fuel toward intake valve **04**.

ECU **3** controls actuators provided to the vehicle, by calculation results based on inputted detection signals of sensors.

There are provided a crank angle sensor **5** arranged to sense a reference crank angle signal REF in reference rotation positions at intervals of the rotational angle of 180 degrees of crank shaft **4**, and to sense a unit angle signal POS; a cam angle sensor **6** arranged to sense a cam signal CAM in the reference rotation positions at intervals of the cam angle of 90 degrees (the crank angle of 180 degrees); an accelerator opening sensor **7** arranged to sense an accelerator opening APS; an air flow meter **8** arranged to sense an intake air quantity Qa of the engine; and a cooling water temperature sensor **9** arranged to sense a cooling water temperature Tw. An engine speed Ne is calculated based on a period of reference crank angle signal REF, or frequency of the detection of unit angle signal POS per unit time.

Moreover, a valve timing control apparatus (VTC) **10** is provided at an one end portion of an intake cam shaft **1**.

As shown in FIGS. **2** and **3**, this VTC **10** includes intake cam shaft **1**; a timing sprocket **11** which is a driving rotational member provided at a front end portion of this intake cam shaft **1**, and arranged to be relatively pivoted; a phase varying mechanism **12** disposed radially inside timing sprocket **11**, and arranged to vary a relative rotational phase between intake cam shaft **1** and timing sprocket **11**; an electromagnetic brake mechanism **13** which is a driving mechanism arranged to provide a driving force to phase varying mechanism **12** by the energization; a crank angle sensor **5** and a cam angle sensor **6** which are phase angle sensing mechanisms arranged to sense relative rotational phase between timing sprocket **11** and cam shaft **1**.

Cam shaft **1** includes two cams **1***a* and **1***a* provided to each cylinder, disposed on an outer surface of cam shaft **1**, and arranged to open intake valve **04**. A driven shaft member **14** is connected with an end portion of cam shaft **1** in the axial direction by a cam bolt **15**.

Driven shaft member **14** includes a cylindrical shaft portion **14***a* having a through hole into which cam bolt **15** is inserted; and a larger diameter portion **14***b* which is a flange shape with a larger diameter, and which is formed integrally with an end portion of shaft portion **14***a* on the cam shaft **1**'s side. A plurality of guide holes **14***c* are formed on an outer surface of shaft portion **14***a* on the larger diameter portion **14***b*'s side.

Timing sprocket **11** includes a gear **11***a* which is a ring shape, which is formed integrally on an outer circumference of timing sprocket **11**, and which is connected through a timing chain (not shown) with the crank shaft **4**; and a driving ring **11***b* which is a substantially circular plate, which is provided radially inside this ring-shaped gear **11***a*, and which includes an inner circumference surface of a through hole formed at a substantially central portion of driving ring **11***b*, and rotatably supported on an outer circumference of larger diameter portion **14***b* of driven shaft member **14**.

Driving ring **11***b* includes three radial window holes **17** which are radial guides, each of which passes through driving ring **11***b*, and each of which extends in the substantially radial direction of timing sprocket **11**. Each of radial window holes **17** has side walls confronting each other, and extending in parallel with each other. There are provided three link members **18** each provided between adjacent two of radial window holes **17**, each inserted into one of radial window holes **17**, and each arranged to be moved in the circumferential direction.

Each of link members **18** is bent into a substantially arc shape. Each of link members **18** includes a first end portion which is a cylindrical shape, and a second end portion which is a cylindrical shape. Three lever protrusions are integrally formed on an inner circumference of an end portion of the larger diameter portion **14***b* of driven shaft member **14** to protrude. One end portion of each pin **19** is inserted into and fixed on, by the press fit, a holding hole penetrating through one of the lever protrusions. The first end portion of link member **18** is rotatably connected with the other end portion of pin **19**.

The second end portion of each link member **18** is inserted into one of radial window holes **17**, and has a receiving hole opened axially in the forward direction. The receiving hole of each link member **18** receives, through one of radial window holes **17**, an engagement pin **21** having a spherical end portion engaged with a spiral groove **25** of a spiral disc **23** described later, and a coil spring **22** arranged to urge this engagement pin **21** in the forward direction (on the spiral groove **25**'s side).

The first end portion of each link member **18** is connected through pin **19** with driven shaft member **14** in a state in which the second end of link member **18** is inserted into the corresponding radial window hole **17**. Accordingly, the first end portion of each link member **18** is moved along the one of guide holes **14***c* when link member **18** is moved along each radial window hole **17** by the external force, so that timing sprocket **11** and driven shaft member **14** are relatively pivoted in a direction and angle which correspond to the displacement of the second end portion.

Spiral disc **23** is rotatably supported through a bearing on an outer circumference of shaft portion **14***a*, on the forward side of driving ring **11***b*. This spiral disc **23** includes an inner circumference portion slidably supported on the outer circumference surface of shaft portion **14***a*; and a disc portion located radially outside of the inner circumference portion. One spiral groove **25** is formed on a rear surface of the disc portion of spiral disc **23** on the cam shaft **1**'s side. Spiral groove **25** has a semicircular section, and is a spiral guide. The end portion of engagement pin **21** of link member **18** is slidably engaged with this spiral groove **25**.

Spiral groove **25** has a diameter which decreases in the rotational direction of timing sprocket **11**. Spiral groove **25** has a constant rate of change in the entirety. When spiral disc **23** is relatively pivoted in the retard direction with respect to the timing sprocket **11** in a state in which each of engagement pins **21** is engaged with spiral groove **25**, the second end portion of link member **18** is introduced by radial window hole **17** and also the spiral shape of spiral groove **25**, and moved radially inwards (in the advance direction). Contrary, when spiral disc **23** is relatively moved in the advance direction, the second end portion of link member **18** is moved radially outwards, and engagement pin **21** is controlled to the most retarded position in the state in which the engagement pin **21** is positioned in the bending portion of winding groove **25**.

When engagement pin **21** is positioned in a groove end region on the most outer circumference portion of spiral groove **25**, VTC **10** is controlled to a position which is slightly in the advance direction, and which is appropriate to the start of the engine.

When spiral disc **23** receives the relative manipulation force with respect to cam shaft **1**, the second end portion of link member **18** is moved in the radial direction within each radial window hole **17** through each spiral groove **25** and the end portion of each engagement pin **21** by the manipulation force. In this case, the relative pivot force is transmitted to timing sprocket **11** and driven shaft member **14** by the operation (movement) of link member **18**.

Electromagnetic brake mechanism **13** includes a torsion spring **26** arranged to urge spiral disc **23** in the rotational direction (the advance direction) of timing sprocket **11**; and a hysteresis brake **27** which is an electromagnetic actuator arranged to brake spiral disc **23** in a direction opposite to the rotational direction (the retard direction) of timing sprocket **11**. The braking force of hysteresis brake **27** is controlled by the current outputted from ECU **3** in accordance with the operating state of the engine. Consequently, spiral disc **23** is relatively pivoted with respect to timing sprocket **11**, or the pivot position of spiral disc **23** and timing sprocket **11** are held.

Hysteresis brake **27** includes a nonmagnetic annular plate **24** fixed on the front end portion of spiral disc **23** through a connection pin **31**; a hysteresis ring **28** fixed on a front end surface of annular plate **24**; an annular coil yoke **29** disposed on a front end portion of hysteresis ring **28**; and an electromagnetic coil **30** received within coil yoke **29**, and arranged to introduce magnetism (magnetic flux) to coil yoke **29**.

Electromagnetic coil **30** is arranged to generate the brake torque to hysteresis ring **28** by the magnetic force generated through coil yoke **29** when ECU **3** performs the duty control of electromagnetic coil **30** by the energization. That is, when hysteresis ring **28** is moved within the magnetic field between pole teeth **32** and **33** by the energization to electromagnetic coil **30**, the braking torque is generated by the deviation between the direction of the magnetic field and the direction of the magnetic flux within hysteresis ring **28**. The braking force is not related to the rotational speed of hysteresis ring **28** (the relative speed between confronting inner and outer circumference surfaces and hysteresis ring **28**). The braking force becomes a constant value substantially proportional to the magnitude of the magnetic field, that is, the magnitude of the exciting current of electromagnetic coil **30**.

Phase varying mechanism **12** includes radial window holes **17** of timing sprocket **11**, link members **18**, engagement pins **21**, spiral disc **23**, and spiral groove **25**.

ECU **3** is configured to calculate the rotational phase of timing sprocket **11** and cam shaft **1** by reference crank angle signal REF and unit angle signal POS of crank angle sensor **5**, and reference cam angle signal CAM of cam angle sensor **6**.

Crank angle sensor **5** is a general or normal one. As shown in FIGS. **4**A and **4**B, crank angle sensor **5** includes a crank disc **40** coaxially attached to the end portion of crank shaft **4**; and a crank vicinity sensor **41**. Crank disc **40** includes targets **40***a* arranged at substantially regular intervals for sensing the rotation of crank shaft **4**. Crank vicinity sensor **41** senses these targets **40***a* to obtain unit angle signal (rotational angle) POS of crank shaft **4**. Besides, reference crank angle signal REF is sensed at the reference rotational angle at the intervals of the crank angle of 90 degrees.

Cam angle sensor **6** is a general or normal one. As shown in FIGS. **5**A and **5**B, cam angle sensor **6** includes a cam disc **42** coaxially attached to the end portion of cam shaft **1**; and a cam vicinity sensor **43**. Cam disc **42** includes targets **42***a* arranged at substantially regular intervals for sensing the rotation of cam shaft **1**. The interval of adjacent two of targets **42***a* is determined so as to sense the rotation angle of cam shaft **1** which corresponds to the rotation of 180 degrees of crank shaft **4**.

That is, in the in-line four cylinder engine, the interval is 90 degrees. In the V-type six cylinder engine, the interval is 120 degrees. Cam vicinity sensor **43** senses these targets **42***a*, and thereby obtains the reference cam angle signal CAM of cam shaft **1**.

FIG. **6** is a timing chart showing the reference crank angle signal REF, the unit angle signal POS, and the reference cam angle signal CAM. ECU **10** is configured to sense a rotational phase θdet by counting the unit angle signal POS from a timing at which cam vicinity sensor **43** senses one of targets **42***a* and the reference cam angle signal CAM is renewed (updated), to a timing at which crank sensor **5** senses the reference crank angle signal REF.

As shown in FIG. **7**, ECU **3** includes an operating state obtaining section S1 configured to obtain operating state information of the internal combustion engine; a target phase setting section S2 configured to set a normal target phase θtg**1** of VTC **10** from the engine operating state obtained at operating state obtaining section S**1**; an actual phase sensing section S**3** configured to sense an actual phase θdet of VTC **10**; an operation angle calculating section S**4** configured to calculate a magnitude θm of the phase angle that VTC **10** is operated (actuated), from normal target phase θtg**1** obtained by target phase setting section S**2** and actual phase θdet obtained by actual phase sensing section S**3**; a target setting section S**5** configured to set a target phase variation pattern θtg in accordance with the magnitude of θm; a manipulation quantity calculating section S**6** configured to calculate an manipulation quantity U based on a difference between target phase variation pattern θtg and actual phase θdet at a certain moment; and a manipulation quantity outputting section S**7** configured to output voltage Vi based on manipulation quantity U calculated by manipulation quantity calculating section S**6**, to VTC **10**.

It is optional to provide operating state obtaining section S**1**—manipulation quantity outputting section S**7** as an electronic circuit independent from ECU **3**. The rotational phase (valve timing) control shown in FIG. **6** starts when the ignition key is brought to the ON state. The rotational phase control is performed at intervals of a predetermined time (for example, 10 ms).

FIG. **8** is a flowchart showing a control process of VTC **10** by ECU **3**. Operating state obtaining section S**1** corresponds to step S**11**. Target phase setting section S**2** corresponds to step S**12**. Actual phase sensing section S**3** corresponds to steps S**13**-S**15**. Operation angle calculating section S**4** corresponds to step S**16**. Target setting section S**5** corresponds to steps S**17**-S**24**. Manipulation quantity calculating section S**6** corresponds to steps S**25**-S**26**. Manipulation quantity outputting section S**7** corresponds to step S**27**.

At step S**11**, operating state obtaining section S**1** is configured to obtain the operating state information of the internal combustion engine such as engine speed Ne, cooling water temperature Tw, and intake air quantity Qa, by the sensors. In this case, the obtained information are substituted, respectively, to Nen, Twn and Qan.

At step S**12**, target phase setting section S**2** is configured to set normal target phase (valve timing) θtg**1** based on the operating state obtained at step S**11**. This normal target phase θtg**1** is set with reference to a map of the target phase set in advance based on Ne, Tw, and index (intake air quantity) Qa showing the engine load.

In this embodiment, it is presumed that response time Tres of VTC **10** is shorter than a holding (continuing) time Tcon of the operating state Accordingly, a duration time Ttg**1** of normal target phase θtg**1** is longer than response time Tres. However, the present invention is applicable in a case in which response time Tres is longer than operating state holding time Tcon.

Actual phase sensing section S**3** is configured to sense actual phase θdet by ECU **3** as described above, and to substitute actual phase θdet to θdetn at step S**14**. In this case, when a following mathematical expression 1 is satisfied, θdet is also substituted to θdets.

$$|\theta tg1-\theta tg1z|>0 \qquad \text{[Mathematical Expression 1]}$$

where θtg**1**z is θtg**1** at last (previous) time.

When the mathematical expression 1 is not satisfied, the process proceeds to step S**15**, and θdet is displaced by θdetn.

In the count of the time, the timing at which target phase angle θtg**1** is varied is T=0.

Operation angle calculating section S**4** is configured to calculate rotational phase angle (operation angle) θm that VTC **10** is acted (operated) actually, by ECU **3** by a following mathematical expression 2 at step S**16**.

$$\theta m=\theta tg1-\theta dets \qquad \text{[Mathematical Expression 2]}$$

Target setting section S**5** is configured to set target phase variation pattern θtg (which is variable with respect to the time) that VTC **10** needs to follow, based on the operation angle θm by ECU **3**.

Target phase variation pattern θtg is a target value pattern that intermediate target phases are set between θdet and θtg**1**. For example, target phase variation pattern θtg becomes as shown in FIG. **9**.

In this way, the intermediate target phases are set, and accordingly it is possible to suppress the overshoot of VTC **10** even in a case in which the operation angle is large and the overshoot tends to increase.

That is, at step S**17**, θm is compared with a threshold value θth. This threshold value θth is set in advance by an experiment and so on. This threshold value θth is set to a maximum operation angle that VTC **10** can perform a desired operation (movement), and that the overshoot falls within a desired magnitude.

$$\theta m>\theta th \qquad \text{[Mathematical Expression 3]}$$

When the mathematical expression 3 is not satisfied, θtg is set to θtg**1** at step S**24**, as shown in a following mathematical expression 4. That is, θtg does not vary the target phase, and θtg becomes constant until θtg**1** varies.

$$\theta tg=\theta tg1 \qquad \text{[Mathematical Expression 4]}$$

When the mathematical expression 3 is satisfied, target phase variation pattern θtg is set to θtg**2** at steps S**18**-S**23**. At step S**18**, 0 is substituted into N. At step S**19**, N+1 is substituted into N, and the process proceeds to step S**20**.

At step S**20**, N×θop and θm are compared. When it is determined that θm is larger, the process returns to step S**19**. When it is determined that θm is smaller, the process proceeds to step S**21**.

At step S**21**, N−1 is substituted into N. At step S**22**, θm−N×θop is set to θr. Subsequently to step S**22**, θtg=θtg**2** is set at step S**23**.

A mathematical expression 5 described later shows one example in which operation angle θm is divided in each fixed (specific) period Top with reference to one phase angle θop.

However, the present invention is not limited to this method. The time period for holding the intermediate target phases may be varied, for example, in each control period. It is optional that the holding time period of the intermediate target phases are not the identical fixed period. Moreover, it is not necessary that the intermediate target phases are divided with reference to the one phase angle. It is optional to set the phase angle difference between the intermediate targets, to arbitrary magnitude.

[Mathematical Expression 5]

$$\theta tg2=\begin{cases}\theta dets+\theta op(0\le Tn<Top)\\ \theta dets+2\times\theta op(Top\le Tn<2\times\mathrm{Top})\\ \vdots\\ \theta dets+N\times\theta op((N-1)\times Top\le Tn<N\times Top)\\ \theta dets+N\times\theta op+\theta r(N\times\mathrm{Top}\le Tn)\end{cases}$$

where N and θr are described later.

Top and θop are set in advance by experiment and analysis. In this embodiment, Top and θop are set so as not to overshoot, and set so as to converge to the target angle in the fastest manner as shown in a solid line of FIG. **10**.

Accordingly, the phase of VTC **10** can be certainly moved in one (given) direction between θdets and θtg**1**.

As shown in a broken line of FIG. **10**, it is possible to set Top to the short period like Top**2** so as to give priority to readiness or quick response of VTC **10** from θdets to θtg**1**, and so as to make the good response as a whole though the overshoot is caused.

N is a maximum value which is calculated at step S**18**-S21, and which satisfies a following mathematical expression 6.

$$\theta m > N \times \theta op \quad \text{[Mathematical Expression 6]}$$

Moreover, θr is a value calculated by a following mathematical expression 7 at step S**22**.

$$\theta r = \theta m - N \times \theta op \quad \text{[Mathematical Expression 7]}$$

Moreover, in the mathematical expression 5, θr is added to the target phase variation pattern at the last (at the end). The responsiveness of VTC **10** is varied by the adding order. For illustration, FIGS. **11**-**13** show examples of θtg**1** when N is 2 and or is not 0.

FIG. **11** shows one example that θr is added at the last. That is, in the phase angle variation per unit time to repeat the increasing and decreasing of the current (duty ratio) applied to electromagnetic coil **30**, θr which is added at the last to reach the target phase is smaller than the phase angle variation θop by which phase varying mechanism **12** starts to vary the phase, and approaches the target phase.

In this example, VTC **10** is moved θr at short time for the small operation angle at the last. Accordingly, it is possible to decrease the arrival time from θdets to θtg**1**.

In a case in which Top is set to Top**2** so as to allow the overshoot to have the readiness (quick response), VTC **10** has a certain speed at an instant when the target phase is switched to θr. Accordingly, it is possible to further improve the readiness.

FIGS. **12** and **13** show examples in which θr is added at a timing other than the last. In the example shown in FIG. **12**, θr added between the first and the last is minimized. In the example shown in FIG. **13**, θr added at the first is minimized.

In this case, the response is arbitrarily set when θop is set. It is possible to set the convergence time to stationary error or the overshooting as the entirety from θdets to θdtg**1**.

At step S**25**, manipulation quantity calculating section S**6** is configured to calculate the manipulation quantity U based on the difference between θtg and θdet. In this example, the PID control is performed. However, the control is not limited to the PID control.

That is, at step S**25**, difference Er between target phase variation pattern θtg and actual phase θdet is calculated.

$$Er = \theta tg - \theta detn \quad \text{[Mathematical Expression 8]}$$

At step S**26**, the manipulation quantity U is calculated by using Er by a following mathematical expression 9.

$$U = Up + Ui + Ud \quad \text{[Mathematical Expression 9]}$$

where Up, Ui and Ud are calculated by following mathematical expressions 10-12.

$$Up = Kp \times Er \quad \text{[Mathematical Expression 10]}$$

$$Ui = Ki \times Er + Uiz \quad \text{[Mathematical Expression 11]}$$

$$Ud = Kd \times (Er - Erz) \quad \text{[Mathematical Expression 12]}$$

where Uiz is Ui at last time (previous time), and Erz is Er at last time (previous time).

At step S**27**, manipulation quantity outputting section S7 is configured to output manipulation quantity U as input voltage Vi to VTC **10**.

In this embodiment, θtg1 is larger than θdets for the assumption of the advance operation. However, the present invention is not limited to the advance operation. The present invention is applicable to the retard operation.

Second Embodiment

FIG. **14** is a flowchart showing a control process of an ECU in a valve control apparatus according to a second embodiment of the present invention. This second embodiment is applied to the retard operation. As shown in FIG. **14**, target setting section S**5** is different from the first embodiment. More specifically, steps S**17** and S**20**, the mathematical expressions 3, 5 and 6, threshold value θth, and θop are different. The other parts are identical to the first embodiment. The overlapping illustrations are omitted.

The setting of threshold value θthr, θopr and Topr will be illustrated. In the first embodiment, for the assumption of the advance operation, threshold value θth is equal to or greater than **0**. In this second embodiment, the retard operation is assumed, operation angle threshold value θthr on the retard angle side is equal to or smaller than 0.

Topr and θopr are set as appropriate step angle on the retard angle side, as a solid line shown in FIG. **15**, like Top and θop. When Topr is set shorter as Topr**2** so as to attain the good readiness (quick response) of VTC **10** from θdets to θotg**1** as shown in the broken line of FIG. **15**, the overshoot may be caused, and however the good response is attained as a whole.

The absolute value of operation angle threshold value θthr may be identical to threshold value θth, or be different value. The absolute value of θopr and Topr may be identical to values in the advance operation, or be different values.

In a case in which the operation characteristics of VTC **10** in the advance operation and in the retard operation are different from each other, the values in the advance operation and in the retard operation can be varied. Accordingly, it is possible to perform control appropriate for the operations.

In this embodiment, target setting section S**5** which is different from the first embodiment, and which is applied to the retard direction is illustrated with reference to steps S**37**-S**44** of FIG. **14**.

At step S**37**, θm and θthr are compared with each other, and it is judged whether or not the target phase is varied. This is judged by a mathematical expression 13, like the mathematical expression 3 of step S**17** of the first embodiment.

$$\theta m < \theta thr \quad \text{[Mathematical Expression 13]}$$

When the mathematical expression 13 is not satisfied, θtg is set to θtg**1**, like the first embodiment. When the mathematical expression 13 is satisfied, the target phase is varied. At steps S**38**-S**41**, θtg**2** is set as shown in a following mathematical expression 14, like the mathematical expression 5 at steps S**18**-S**23** of FIG. **8** of the first embodiment. The timing of adding θr is identical to the timing in the first embodiment.

[Mathematical Expression 14]

$$\theta tg2 = \begin{cases} \theta dets + \theta op(0 \leq Tn < \mathrm{Top}) \\ \theta dets + 2 \times \theta op(Top \leq Tn < 2 \times \mathrm{Top}) \\ \vdots \\ \theta dets + N \times \theta op((N-1) \times Top \leq Tn < N \times Top) \\ \theta dets + N \times \theta op + \theta r(N \times \mathrm{Top} \leq Tn) \end{cases}$$

At steps S**38**-S**43**, N is determined, like steps S**18**-S**23** of FIG. **8** of the first embodiment. In the first embodiment, the switching is performed as the mathematical expression 6 at step S**20**. However, in this embodiment, the switching is performed as a following mathematical expression 15 at step S**40**.

$$\theta m < N \times \theta op \quad \text{[Mathematical Expression 15]}$$

In the second embodiment for the retard operation, target setting section S**5** sets θtg as described above, unlike the first embodiment. The other operations are identical to the operations of the first embodiment.

In the first and second embodiments, the target phase is varied only in one of the advance operation and the retard operation. It is optional to vary the target phase in both of the advance operation and the retard operation by combining the first and second embodiments.

As mentioned above, the concept of the present invention is to increase the driving force of VTC **10** immediately after the start of the operation, by dividing the target phase, and to decrease the driving force of VTC **10** at a timing to converge the target phase. Accordingly, it is possible to decrease the overshoot of VTC **10** without performing complex calculation, and without varying the control gain in the various conditions.

That is, in the conventional VTC, as shown in a dashed line of FIG. **16**, the movement is slow for the influence of the sliding resistance during first fixed (specific) period T**1** after the start of the operation. The movement is fast during the second fixed (specific) period T**2**. Consequently, the overshoot tends to generate at the operation of VTC **10**.

In these embodiments of the present invention, in a case in which the target operation angle (variation quantity) is divided to, for example, two steps without varying the control gain, as shown in a solid line of FIG. **16**, it is possible to ease the over-speed in the second half of the operation. Moreover, it is possible to suppress the overshoot.

Moreover, crank angle sensor **5** and cam angle sensor **6** which are phase angle sensing mechanism are not high accuracy, and are general (normal) ones. Accordingly, it is possible to suppress the increase of the cost.

The present invention is not limited to these embodiments. For example, the VTC may be provided on the exhaust valve side. It is optional to apply to a structure in which the phase varying mechanism is driven by an electromotive motor and so on without employing the electromagnetic brake of the valve timing control apparatus.

In the embodiments according to the present invention, a valve timing control apparatus for an internal combustion engine which is configured to control an opening timing or a closing timing of an intake valve or an exhaust valve, the valve timing control apparatus includes: a phase varying mechanism arranged to vary a relative rotational phase of a cam shaft with respect to a crank shaft; a driving mechanism arranged to provide a driving force to the phase varying mechanism by energization; a control mechanism configured to control a current applied to the driving mechanism; and a phase angle sensing mechanism arranged to sense the relative rotational phase of the cam shaft with respect to the crank shaft, and to have a detection period longer than a control period of the control mechanism in accordance with an engine operating state. The control mechanism is configured to repeat increasing and decreasing of the current applied to the driving mechanism when the phase varying mechanism continuously varies the relative rotational phase of the cam shaft with respect to the crank shaft by a predetermined angle or more.

In the embodiments according to the present invention, a valve timing control apparatus for an internal combustion engine which is configured to control an opening timing or a closing timing of an intake valve or an exhaust valve, the valve timing control apparatus includes: a phase varying mechanism arranged to vary a relative rotational phase of a cam shaft with respect to a crank shaft; a driving mechanism arranged to provide a driving force to the phase varying mechanism by energization; a control mechanism configured to perform a duty control of a current applied to the driving mechanism; and a phase angle sensing mechanism arranged to sense the relative rotational phase of the cam shaft with respect to the crank shaft, and to have a detection period longer than a control period of the control mechanism in accordance with an engine operating state. The control mechanism is configured to repeat increasing and decreasing of a duty ratio for the driving mechanism when the phase varying mechanism continuously varies the relative rotational phase of the cam shaft with respect to the crank shaft by a predetermined angle or more.

In the embodiments of the present invention, the valve timing control apparatus repeats to increase and decrease the duty ratio and the current applied to the driving mechanism from the control mechanism when the phase varying mechanism varies in series the relative rotational phase a predetermined angle or more. Accordingly, the driving force of VTC **10** is increased immediately after the start of the operation, and decreased at a timing to converge the target phase. Accordingly, it is possible to prevent the overshoot of VTC **10** without performing complex calculation, and without varying the control gain in the various conditions.

In the embodiments of the present invention, the general or normal crank angle sensor and the general or normal cam angle sensor are used. Accordingly, it is possible to suppress the increasing of the cost.

The entire contents of Japanese Patent Application No. 2008-37061 filed Feb. 19, 2008 are incorporated herein by reference.

Although the invention has been described above by reference to certain embodiments of the invention, the invention is not limited to the embodiments described above. Modifications and variations of the embodiments described above will occur to those skilled in the art in light of the above teachings. The scope of the invention is defined with reference to the following claims.

What is claimed is:

1. A valve timing control apparatus for an internal combustion engine which is configured to control an opening timing or a closing timing of an intake valve or an exhaust valve, the valve timing control apparatus comprising:

a phase varying mechanism arranged to vary a relative rotational phase of a cam shaft with respect to a crank shaft;

a driving mechanism arranged to provide a driving force to the phase varying mechanism by energization;

a control mechanism configured to control a current applied to the driving mechanism; and

a phase angle sensing mechanism arranged to sense a relative rotational phase of the cam shaft with respect to the crank shaft, and to have a detection period longer than a control period of the control mechanism in accordance with an engine operating state,

wherein, during operation, the control mechanism repeats increasing and decreasing of the current applied to the driving mechanism when the phase varying mechanism continuously varies the relative rotational phase of the cam shaft with respect to the crank shaft by at least a predetermined angle, and does not repeat increasing and decreasing of the current applied to the driving mechanism when the phase varying mechanism does not continuously vary the relative rotational phase of the cam shaft with respect to the crank shaft by at least the predetermined angle.

2. The valve timing control apparatus as claimed in claim **1**, wherein, during operation, the control mechanism varies a phase angle variation per unit time to repeat the increasing and decreasing of the current applied to the driving mechanism.

3. The valve timing control apparatus as claimed in claim **2**, wherein the phase angle variation per unit time includes a last variation to reach a target phase, which is smaller than a variation that the phase varying mechanism starts to vary the phase, and approaches the target phase.

4. The valve timing control apparatus as claimed in claim **2**, wherein the phase angle variation per unit time includes a variation which is between a first variation that the phase varying mechanism starts to vary the phase, and a last variation to reach a target phase, and which is smaller than the first variation and the last variation.

5. The valve timing control apparatus as claimed in claim **2**, wherein the phase angle variation per unit time includes a first variation that the phase varying mechanism starts to vary the phase, and that is smaller than a variation other than the first variation.

6. The valve timing control apparatus as claimed in claim **1**, wherein a longest period of periods to repeat the increasing and decreasing of the current applied to the driving mechanism is a period in which the phase varying mechanism does not generate an overshoot.

7. The valve timing control apparatus as claimed in claim **1**, wherein, during operation, the control mechanism sets a target value of a phase angle varied by the phase varying mechanism from the engine operating state, calculates an actual phase of the cam shaft with respect to the crank shaft, determines a phase angle for a movement from the actual phase to the target value, and sets a period to repeat the increasing and decreasing of the current applied to the driving mechanism when the phase angle for the movement from the actual phase to the target value is equal to or greater than a predetermined angle.

8. The valve timing control apparatus as claimed in claim **1**, wherein the driving mechanism is arranged to provide the driving force to the phase varying mechanism by directly providing, to the phase varying mechanism, an electromagnetic force generated by the energization.

9. The valve timing control apparatus as claimed in claim **8**, wherein the driving mechanism is an electromagnetic brake mechanism.

10. The valve timing control apparatus as claimed in claim **8**, wherein the driving mechanism is an electromotive motor.

11. A valve timing control apparatus for an internal combustion engine which is configured to control an opening timing or a closing timing of an intake valve or an exhaust valve, the valve timing control apparatus comprising:

a phase varying mechanism arranged to vary a relative rotational phase of a cam shaft with respect to a crank shaft;

a driving mechanism arranged to provide a driving force to the phase varying mechanism by energization;

a control mechanism configured to perform a duty control of a current applied to the driving mechanism; and

a phase angle sensing mechanism arranged to sense a relative rotational phase of the cam shaft with respect to the crank shaft, and to have a detection period longer than a control period of the control mechanism in accordance with an engine operating state,

wherein, during operation, the control mechanism repeats increasing and decreasing of a duty ratio for the driving mechanism when the phase varying mechanism continuously varies the relative rotational phase of the cam shaft with respect to the crank shaft by at least a predetermined angle, and does not repeat increasing and decreasing of a duty ratio for the driving mechanism when the phase varying mechanism does not continuously vary the relative rotational phase of the cam shaft with respect to the crank shaft by at least the predetermined angle.

12. The valve timing control apparatus as claimed in claim **11**, wherein, during operation, the control mechanism varies a phase angle variation per unit time to repeat the increasing and decreasing of the duty ratio.

13. The valve timing control apparatus as claimed in claim **12**, wherein the phase angle variation per unit time includes a last variation to reach a target phase, which is smaller than a variation that the phase varying mechanism starts to vary the phase, and approaches the target phase.

14. The valve timing control apparatus as claimed in claim **12**, wherein the phase angle variation per unit time includes a variation which is between a first variation that the phase varying mechanism starts to vary the phase, and a last variation to reach a target phase, and which is smaller than the first variation and the last variation.

15. The valve timing control apparatus as claimed in claim **12**, wherein the phase angle variation per unit time includes a first variation that the phase varying mechanism starts to vary the phase, and that is smaller than a variation other than the first variation.

16. The valve timing control apparatus as claimed in claim **11**, wherein a longest period of periods to repeat the increasing and decreasing of the duty ratio is a period in which the phase varying mechanism does not generate an overshoot.

17. The valve timing control apparatus as claimed in claim **11**, wherein, during operation, the control mechanism sets a target value of a phase angle varied by the phase varying mechanism from the engine operating state, calculates actual phase of the cam shaft with respect to the crank shaft, determines a phase angle for a movement from the actual phase to the target value, and sets a period to repeat the increasing and decreasing of the duty ratio when the phase angle for the movement from the actual phase to the target value is equal to or greater than a predetermined angle.

18. The valve timing control apparatus as claimed in claim **11**, wherein the driving mechanism is arranged to provide the driving force to the phase varying mechanism by directly providing, to the phase varying mechanism, an electromagnetic force generated by the energization.

19. A valve timing control apparatus for an internal combustion engine which is configured to control an opening timing or a closing timing of an intake valve or an exhaust valve, the valve timing control apparatus comprising:

a phase varying mechanism arranged to vary a relative rotational phase of a cam shaft with respect to a crank shaft;

a driving mechanism arranged to provide a driving force to the phase varying mechanism by energization;

a control mechanism configured to control a current applied to the driving mechanism; and

a phase angle sensing mechanism arranged to sense a relative rotational phase of the cam shaft with respect to the crank shaft, and to have a detection period longer than a control period of the control mechanism in accordance with an engine operating state, wherein, during operation, the phase varying mechanism repeats increasing and decreasing of a movement speed when the phase varying mechanism continuously varies the relative rotational phase of the cam shaft with respect to the crank shaft by at least a predetermined angle, and does not repeat increasing and decreasing of a movement speed when the phase varying mechanism does not continuously vary the relative rotational phase of the cam shaft with respect to the crank shaft by at least the predetermined angle.

20. The valve timing control apparatus as claimed in claim **19**, wherein, during operation, the driving mechanism repeats increasing and decreasing of the driving force when the phase varying mechanism continuously varies the relative rotational phase of the cam shaft with respect to the crank shaft by at least the predetermined angle.

21. A valve timing control apparatus for an internal combustion engine that is configured to control an opening timing or a closing timing of an intake valve or an exhaust valve, the valve timing control apparatus comprising:

a phase varying mechanism configured to vary a relative rotational phase angle of a cam shaft with respect to a crank shaft;

a driving mechanism configured to provide a driving force to the phase varying mechanism;

a control mechanism configured to control a current applied to the driving mechanism; and

a phase angle sensing mechanism configured to sense an actual relative rotational phase angle of the cam shaft with respect to the crank shaft,

wherein, to reach a target relative rotational phase angle during operation, the control mechanism (i) performs a plurality of modifications of the current applied to the driving mechanism when a difference between the target relative rotational phase and the actual relative rotational phase angle is greater than a threshold angle, and (ii) performs a single modification of the current applied to the driving mechanism when a difference between the target relative rotational phase angle and the actual relative rotational phase angle is less than the threshold angle.

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